KSÜ Tarım ve Doğa Derg 27 (5), 1148-1158, 2024
KSU J. Agric Nat 27 (5), 1148-1158, 2024
DOI:10.18016/ksutarimdoga.vi.1226330

Biomass Yield in Bread Wheat: The Effect of Sowing Density and Predicting Using NDVI

Ali Cevat SÖNMEZ[1]✉
[1]Transitional Zone Agriculture Research Institute, Department of Cereal Breeding, Ziraat Cad. No: 396 Tepebaşı, Eskişehir, Türkiye
[1]https://orcid.org/0000-0002-9818-2660
✉: alicevatsonmez@gmail.com

ABSTRACT

This is due to approaching the upper limits of the harvest index. The study aimed to determine the effect of sowing density (SD) practices on BY in the Central Anatolian Region and the use of normalized vegetation index (NDVI) values in estimating BY easily. Field trials were carried out for three consecutive years in rainfed and irrigated conditions in Eskişehir between 2012 and 2015. Four different SDs (Sparse, Ordinary, High, and Very High) were applied to six winter wheat cultivars. Biomass samples were taken during flowering and harvesting periods. NDVI values were measured using the Green Seeker Handhold Sensor (GSHS) tool during the flowering period. In both conditions, the correlation between the NDVI values during the flowering period and the biomass yields obtained during the harvesting period was found to be positive and significant (in rainfed conditions (R = 0.837), in irrigated conditions (R = 0.786)). To obtain high BY, it is recommended that to be sowed with High SD in rainfed conditions, and Ordinary SD practices in irrigated conditions. Considering the varieties, Alpu 2001 and Harmankaya-99 stand out from the others in terms of getting high biomass yield in both conditions. In addition, it was determined that the GSHS is a reliable tool that can be used for the estimation of BY.

Field Crops

Research Article

Article History
Received : 29.12.2022
Accepted : 12.12.2023

Keywords
Triticum aestivum L.
Biomass estimation
Seeding rate
Vegetation Index
Correlation

Ekmeklik Buğdayda Biyokütle Verimi: Ekim Sıklığının Etkisi ve NDVI Kullanılarak Tahmini

ÖZET

Bu çalışmanın amacı, İç Anadolu Bölgesi'nde ekim sıklığı(ES) uygulamalarının BV'ye etkisini ve BV'nin kolayca tahmin edilmesinde normalize edilmiş bitki indeksi (NDVI) değerlerinin kullanımını belirlemektir. Tarla denemeleri 2012-2015 yılları arasında arka arkaya üç yıl süreyle yağmura bağımlı ve sulu koşullarda Eskişehir'de yapılmıştır. Altı adet kışlık buğday çeşidine dört farklı ekim sıklığı (Seyrek, Sıradan, Yüksek ve Çok Yüksek) uygulanmıştır. Biyokütle örnekleri çiçeklenme ve hasat dönemlerinde alınmıştır. NDVI değerleri çiçeklenme döneminde Green Seeker Handhold Sensor (GSHS) cihazı kullanılarak ölçülmüştür. Her iki koşulda da çiçeklenme dönemindeki NDVI değerleri ile hasat döneminde elde edilen BV'leri arasındaki korelasyon pozitif ve istatistiksel olarak önemli bulunmuştur (yağmura bağımlı koşullarda (R = 0,837), sulu koşullarda (R = 0,786)). Yüksek BV elde etmek için çeşitlerin yağışlı koşullarda Yüksek ES uygulamasıyla, sulu koşullarda Normal ES uygulamasıyla ekilmesi önerilir. Çeşitler arasında Alpu 2001 ve Harmankaya-99 çeşitlerinden her iki koşulda da yüksek verim alınmıştır. Ayrıca GSHS'nin BV tahmini için kullanılabilecek güvenilir bir araç olduğu belirlenmiştir.

Tarla Bitkileri

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 29.12.2022
Kabul Tarihi : 12.12.2023

Anahtar Kelimeler
Triticum aestivum L.
Biyokütle Tahmini
Tohum sıklığı
Vejetasyon indeksi
Korelasyon

Atıf Şekli: Sönmez, A.C. (2024). Ekmeklik Buğdayda Biyokütle Verimi: Ekim Sıklığının Etkisi ve NDVI Kullanılarak Tahmini. *KSÜ Tarım ve Doğa Derg 27* (5), 1171-1181. DOI: 10.18016/ksutarimdoga.vi.1226330.
To Cite : Sönmez, A.C (2024). Biomass Yield in Bread Wheat: The Effect of Sowing Density and Predicting Using NDVI. *KSU J. Agric Nat 27* (5), 1171-1181. DOI: 10.18016/ksutarimdoga.vi.1226330.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is an ancient nutritionally important field crop grown worldwide. It is also the most widely used crop for making bread, which is one of the most consumed foods worldwide and has a sacred status in many religions (Shewry, 2009). Knowledge of the various physiological traits associated with genetic gains in yield potential is essential for understanding yield-limiting factors and informing future breeding strategies (Aisawi et al., 2015). Thanks to effective breeding strategies, wheat grain yield (GY) has increased tremendously over the last five decades (Lovegrove et al., 2020). However, to meet the food needs of the world population, which is expected to reach 9.8 billion by 2050 (Anonymous, 2022), additional increases in wheat yield per unit area are required (Reynolds et al., 2022). In the studies carried out so far, shortening of plant height has led to an increase in yield due to an improvement in the harvest index, but the harvest index has approached the upper limit of significance (Foulkes et al., 2011). The challenges of increasing the harvest index also emphasize the importance of improving biomass in recent years (Reynolds et al., 2017; Savaşlı et al., 2023). There is a need to increase biomass yields due to its use in many industries such as food, paper production, energy, and especially livestock (Foulkes et al., 2007; Khan & Mubeen, 2012; Dai et al., 2016; Ravindran & Jaiswal, 2016; Townsend et al., 2018). Increasing total biomass production seems inevitable to achieve higher grain yields (Reynolds et al., 2012; Mitchell & Sheehy, 2018; Savaşlı et al., 2023). Crossing and selecting germplasm solely for biomass yield seems to be insufficient, as negative relationships between biomass yield and grain yield often lead to inappropriate and off-target results (Aisawi et al., 2015). For many reasons, high biomass yield has become one of the most sought-after traits in wheat agriculture (Molero et al., 2019). Higher total biomass yields can result from increasing the light-blocking and radiation-use efficiency of the plant or its component traits (Reynolds et al., 2020).

Since sowing density is shaped under the influence of both genotype and environment, it may vary according to the annual rainfall amount and distribution, soil characteristics, agricultural techniques applied, and the variety of characteristics to be grown. In this respect, it is important to determine the optimum sowing density in each region and variety. Many researchers have reported that the relationship between planting density and photosynthetic efficiency, nitrogen use efficiency, and nutrient and water use efficiency of plants positively affects plant growth (Carr et al., 2003; Amanullah et al., 2010; Khan et al., 2020; Shah et al., 2020). Sowing density is one of the agronomic practices that have a significant effect on obtaining high grain yield and biomass yield per unit area (Bhatta et al., 2017; Ma et al., 2018; Khan et al., 2020). In this study, it was aimed to determine the optimum sowing density to obtain high biomass yield by investigating the effect of different planting frequencies on the biomass yield of bread wheat varieties under rainfed and irrigated conditions.

Measuring the biomass yield of wheat is both difficult and time-consuming for wheat breeders and agronomists. Therefore, they need new reliable methods to measure biomass yield more easily (Walter et al., 2019; Atkinson Amorim et al., 2022; Savaşlı et al., 2023). Optical sensors can be widely used to estimate yield and biomass characteristics in wheat (Savaşlı et al.,2021a). Normalized vegetation index (NDVI) data has been used successfully by many scientists in different regions of the world (Gündoğdu, 2018). The use of vegetation index is one of the reliable methods of biomass yield estimation for researchers willing to work with a large number of genotypes, as it allows rapid and non-destructive assessment of plant traits. (Cabrera-Bosquet et al., 2011; Zecha et al., 2018; Chandel et al., 2019; Savaşlı et al., 2023). To make better use of such new methods, it is necessary to test whether their use is appropriate for the plant variety and region (Savaşlı et al., 2021b). In this study, it was aimed to measure the effect of planting density on biomass yield as well as the usability of the Green Seeker Hand Sensor (Lapidus et al., 2022) to estimate biomass yield easily and quickly.

MATERIALS and METHODS

Trial area, soil properties, and climate data

Field trials were conducted for three consecutive years between 2012 and 2015 crop years in the central campus of the Transitional Zone Agricultural Research Institute, Eskişehir (39° 46' N, 30° 24' E, 780 m above sea level). Soil samples taken from 0-50 cm depth before sowing were examined at the Soil-Water Research Laboratory of the Transitional Zone Agricultural Research Institute and analyzed as clay loam with a slightly alkaline structure and no salinity. It was also classified as moderately calcareous, with low organic matter and phosphorus content and a high content of plant-useful potassium. Total annual rainfall was 254.1 mm, 318.7 mm, and 643.0 mm, respectively. The highest rainfall occurred in the 2014-15 crop year, but this rainfall was not effective enough to increase biomass yields due to the maturing period of wheat. This high rainfall in the 2014-15 crop year positively affected biomass yield in rainfed trials as expected, but not in irrigated trials due to the increase in lodging and diseases (Table 1).

Plant materials and crop cultivation

Six winter wheat (*Triticum aestivum* L.) cultivars released between 1969 and 2001 years by the Transitional Zone Agricultural Research Institute were used as plant material. The cultivars are grown widely in the Central Anatolia Region. Alpu 2001, Atay-85, and Sultan 95 are white-grained, awned cultivars recommended for irrigated areas. Bezostaja1, Harmankaya-99, and Sönmez 2001 are red grain varieties that are recommended for rainfed areas

Table 1. The precipitation (mm) and air temperature data (°C) for the average of years and long years in which the trials were conducted in Eskişehir.
Çizelge 1. Eskişehir'de denemelerin yapıldığı yıllara ve uzun yıllara ait yağış (mm) ve hava sıcaklığı verileri (°C)

	Precipitations (mm)				Air temperature (°C)			
Months	2012-13	2013-14	2014-15	Long years*	2012-13	2013-14	2014-15	Long years**
October	0.0	2.0	41.4	14.5	18.7	16.7	18.4	17.1
September	16.1	65	66.1	27.2	14.2	9.8	13.6	11.9
November	14.5	15	26.2	29.3	7.3	6.7	7.6	6.4
December	73.2	1.5	72.1	45.1	2.2	1.7	5.8	2.0
January	18.5	21	39.0	38.4	1.7	3.6	0.8	-0.2
February	36.5	7.0	60.9	32.3	4.3	6.0	2.3	1.3
March	33.2	27.1	46.0	33.6	7.1	6.2	5.1	4.9
April	37.8	23.2	41.3	35.1	10.8	11.3	7.1	10.2
May	9.5	53.8	61.2	44.9	17.7	16.4	14.9	15
June	14.0	70.5	125.3	30.5	20.0	19.9	16.3	18.8
July	0.8	20.4	0.0	13.8	21.6	23.7	21.0	21.5
Agust	0.0	12.2	63.5	7.8	22.4	24.1	21.7	21.4
Monthly average	21.2	26.6	53.6	29.4	12.3	12.2	11.2	10.9
Annual total	254.1	318.7	643.0	352.5	148	146.1	134.6	130.3

*: Means of between 1995-2015 years; **: Means of between 1925 - 2015 years

and Bezostaja1 and Sönmez 2001 have awnless spikes Sowing density amounts were determined to cover one degree below and one degree above the normal and high sowing densities currently practiced in the Central Anatolia Region. According to this, four sowing density treatments were used (SSD: Sparse Sowing Density is 350 seeds m^{-2}; OSD: Ordinary Sowing Density is 500 seeds m^{-2}; HSD: High Sowing Density is 650 seeds m^{-2} and VHSD: Very High Sowing Density is 800 seeds m^{-2}). Drilling was done by a six-row plot seeder on a plot size 7.0 x 1.2 m and 20 cm distance between rows. The plot size was 6 m^2 (1.2 m x 5 m) and drilled on the second week of October in all three years. The fertilizing was made 70 kg ha^{-1} N and 70 kg ha^{-1} P for rainfed trials and 120 kg ha^{-1} N and 90 kg ha^{-1} P for irrigated trials. Half of the nitrogen fertilizer was given at drilling and the rest was given in spring at the tillering stage Zadoks Growth Stage (GS) 25 (Zadoks et al., 1974). Field trials were conducted in rainfed and irrigated conditions. The irrigated trials were watered three times (after sowing, at stem-elongation and heading stages) by sprinkler method with 40 mm of water. To control broadleaf weeds in all three years of the experiment, an herbicide with 2-4 D 2-Ethylhexyl ester + 6.25 g/l Florasulam active ingredient was applied to the plots at a dose of 1500 mL ha-1 before the stem-elongation period using a sprayer method under windless and suitable temperature conditions.

Data collection and statistical analyses

Flowering biomass yield (FBY) was measured at the anthesis stage (GS 65) and harvesting biomass yield (HBY) was measured at the harvest stage (GS 94). Biomass samples were taken from the soil surface at both ends of the plots using a knife and a 50 cm line was selected from the middle rows considering the edge effect. They were immediately placed in a plastic bag to prevent moisture loss and weighed in the laboratory. Thus, the total green plant weight was obtained. After, randomly selected 50 spiked plants were weighed and placed in a paper bag. Then, drying at 75 °C for 48 hours, it was weighed again and the dry weight of the sub-sample was obtained. The biomass yields were calculated according to Önder (2007). NDVI values were obtained at the flowering (GS 65) stage by using the Green Seeker Handheld Crop Sensor (Savaşlı et al., 2021b). Field trials were set up in randomized complete blocks according to factorial experimental design with three replications. A gap of 30 m was left as an isolation distance between rainfed and irrigated trials. The rainfed and irrigated trials were analyzed separately. Statistical analysis was performed using the JMP statistical software (JMP, 2016). The equality of variances was checked with Levene's test to determine whether the multiyear data were suitable for analyses by combining them. The significance of the differences among sowing densities, cultivars, years, and interactions was determined by analysis of variance. After testing the significance of treatment effects by analysis of variance, means were compared using Student's t method (Student, 1908). The Least Significant Difference (LSD) test was used to compare the means.

RESULTS

Flowering period biomass yield (FBY)

According to the results of the analysis of variance, the differences between years were found significant in both rainfed and irrigated conditions (Table 2). The highest average FBY was obtained in 2014-15 years at 11.13 t ha^{-1} under rainfed conditions and 13.45 and

13.34 t ha^{-1} under irrigated conditions in 2012-13 and 2014-15 years, respectively (Table 3). The differences between sowing density treatments were significant only in rainfed conditions and the highest average FBY value was obtained from VHSD application with 10.31 t ha^{-1}. Although the difference was not significant in irrigated conditions, the highest value was obtained from the OSD treatment with 13.38 t ha^{-1}. While linear increases were observed in rainfed conditions and a parabolic curve was observed in irrigated conditions. The effect of cultivars was significant only in irrigated conditions and Alpu 2001, Harmankaya-99, and Sultan 95 cultivars stood out with 13.81, 13.85, and 13.05 t ha^{-1} respectively. The mean FBY value was obtained in irrigated conditions with 12.92 t ha^{-1} and the average FBY value was 33% higher than the rainfed conditions with 9.72 t ha^{-1}. In addition, since the cultivars showed different performances according to the mean of years, the Year x Genotype interaction was found to be significant in irrigated conditions. For instance, in the 2012-13 season, the Harmankaya-99 cultivar came to the forefront, while the Alpu 2001 cultivar came to the forefront in 2013-14, and no difference was observed between the cultivars in 2014-15. Similarly, since the performance of SD treatments in irrigated conditions differed between years, the Year x Sowing Density interaction was also found significant (Table 2). While OSD and HSD were prominent in 2012-13, there was no difference between SD applications in other years (Table 3).

Harvesting period biomass yield (HBY)

According to the results of the analysis of variance, the differences between years, sowing densities, and genotypes were found statistically significant in both rainfed and irrigated conditions (Table 2). When the years were analyzed, the highest HBY was acquired in 2014-15, the year with the highest rainfall with 9.90 and 11.75 t ha^{-1}, under both rainfed and irrigated conditions, respectively (Table 4). This was followed by the years 2013-14 and 2012-13, respectively. Considering the SD applications in Table 4, the highest average HBY values were obtained from VHSD and HSD applications in rainfed conditions with 8.97 and 8.73 t ha^{-1} respectively. In irrigated conditions, OSD application stood out with 11.49 t ha^{-1}. The effect of increasing sowing density on HBY values was positive and linear in rainfed conditions, while it was positive and quadratic in irrigated conditions. When looking at the cultivars, Alpu 2001, Harmankaya-99 and Bezostaja1 cultivars stood out in both cases according to the average HBY values. While 9.01, 8.97, and 8.26 t ha^{-1} were obtained in rainfed conditions respectively, 11.97 and 11.41 t ha^{-1} were obtained in irrigated conditions, respectively. It was determined that the average HBY value was obtained at 10.88 t ha^{-1} in irrigated conditions and it was 31% higher than in rainfed conditions. In addition, the Years x Genotype interaction was found to be significant due to the different performances of cultivars in both conditions. According to the mean values, it was determined that the differences between the cultivars were significant and they showed similar performance in both conditions. While Alpu 2001 and Harmankaya-99 cultivars stood out in the 2012-13 years, only the Alpu 2001 cultivar was prominent in the 2013-14 season in both conditions. In the 2014-15 season, all cultivars except Atay-85 were similar to each other under rainfed conditions. Again, according to the average values, since sowing density treatments showed different performance in both conditions according to years, the interaction of Years x Sowing Density was found to be significant (Table 2). In rainfed conditions, HSD and VHSD stood out with 8.73 and 8.97 t ha^{-1}, respectively, while in irrigated conditions, OSD values stood out with 11.49 t ha^{-1}.

Normalized difference vegetation index (NDVI)

According to the results of the analysis of variance, the differences between years, sowing densities, and genotypes were significant in terms of NDVI in both rainfed and irrigated conditions (Table 2).

Table 2. Analysis of variance table with mean squares for biomass yields and NDVI values
Çizelge 2. Biyokütle verimleri ve NDVI değerlerinin kareler ortalaması ve varyans analiz tablosu

		FBY		HBY		NDVI	
Source of variation	Df	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Years (Y)	2	144.41**	49.25**	205.11**	41.59**	285.20**	69.59**
Sowing density (SD)	3	14.23*	8.79	23.49**	9.00*	133.86**	48.18**
Genotypes (G)	5	6.17	27.51**	11.82**	21.74**	22.04*	33.63**
Error	108	3.66	3.91	2.08	2.91	7.91	563.33
Y x G	10	5.22	12.46**	4.42*	8.16*	306.90**	23.54**
Y x SD	6	6.4	9.05*	8.43*	11.28**	24.69**	7.13
SD x G	15	3.07	1.71	2.76	1.57	6.90	5.74
Y x SD x G	30	3.62	4.06	3.49	4.3	5.79	6.92

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns: Not significant; Df: Degree of freedom; FBY: Flowering period biomass yield; HBY: Harvest period biomass yield; NDVI: Normalized difference vegetation index

Table 3. Flowering period biomass yield values ($t\ ha^{-1}$) and comparison of its means in both conditions
Çizelge 3. Çiçeklenme dönemi biyokütle verimi değerleri ($t\ ha^{-1}$) ve her iki koşulda ortalamaların karşılaştırılması

	Rainfed			
Treatment	2012-2013	2013-2014	2014-2015	Mean
Sowing density				
SSD	7.04 ± 0.30 b	9.78 ± 0.32 a	11.02 ± 0.31 ab	9.28 ± 0.44 b
OSD	8.14 ± 0.62 a	9.21 ± 0.71 a	10.42 ± 0.45 b	9.29 ± 0.40 b
HSD	8.93 ± 0.33 a	10.18 ± 0.42 a	10.88 ± 0.32 ab	10.00 ± 0.28 ab
VHSD	9.01 ± 0.61 a	9.82 ± 0.44 a	12.21 ± 0.71 a	10.31 ± 0.46 a
LSD (0.05)				0.73*
Varieties				
Alpu 2001	8.09 ± 0.65 a	11.16 ± 0.55 a	11.38 ± 0.59 a	10.22 ± 0.56 a
Atay-85	7.96 ± 1.26 a	9.43 ± 0.32 b	10.25 ± 0.36 a	9.21 ± 0.50 b
Bezostaja1	8.51 ± 0.82 a	8.61 ± 0.65 b	11.96 ± 0.72 a	9.66 ± 0.61 ab
Harmankaya-99	8.98 ± 0.52 a	9.77 ± 0.60 ab	11.90 ± 1.01 a	10.22 ± 0.54 a
Sönmez 2001	8.12 ± 0.52 a	9.39 ± 0.46 b	10.75 ± 0.09 a	9.42 ± 0.39 ab
Sultan 95	8.03 ± 0.33 a	10.12 ± 0.24 a	10.55 ± 0.47 a	9.58 ± 0.38 ab
LSD (0.05)				ns
Means of years	8.28 ± 0.28 C	9.75 ± 0.24 B	11.13 ± 0.26 A	9.72**
CV (%)	17.75	19.28	20.64	19.68
Sowing density				
SSD	12.69 ± 0.74 c	11.38 ± 0.63 b	13.12 ± 0.50 a	12.40 ± 0.39 b
OSD	14.29 ± 1.10 a	13.06 ± 0.34 a	12.80 ± 0.62 a	13.38 ± 0.44 a
HSD	13.98 ± 0.98 ab	11.60 ± 0.23 b	13.38 ± 0.27 a	12.98 ± 0.41 ab
VHSD	12.82 ± 0.93 bc	11.82 ± 0.61 ab	14.05 ± 0.57 a	12.90 ± 0.45 ab
LSD (0.05)				ns
Varieties				
Alpu 2001	14.11 ± 0.94 bc	13.43 ± 0.67 a	13.88 ± 0.44 a	13.81 ± 0.38 ab
Atay-85	12.71 ± 0.45 c	11.33 ± 0.93 b	13.07 ± 0.65 a	12.37 ± 0.43 cd
Bezostaja1	10.45 ± 0.47 d	11.30 ± 0.29 b	12.94 ± 0.28 a	11.56 ± 0.36 d
Harmankaya-99	15.84 ± 1.03 a	11.81 ± 0.68 b	13.91 ± 0.37 a	13.85 ± 0.63 a
Sönmez 2001	13.19 ± 0.98 bc	11.57 ± 0.43 b	13.80 ± 1.08 a	12.85 ± 0.54 bc
Sultan 95	14.38 ± 1.03 ab	12.34 ± 0.21 ab	12.42 ± 0.60 a	13.05 ± 0.46 abc
LSD (0.05)				0.96**
Means of years	13.45 ± 0.46 A	11.96 ± 0.26 B	13.34 ± 0.26 A	12.92**
CV (%)	13.29	16.20	16.47	15.30

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; ns: Not significant; LSD: Least significant difference; CV: Coefficient variation; SSD: Sparse sowing density; OSD: Ordinary sowing density; HSD: High sowing density; VHSD: Very High sowing density

Looking at the mean NDVI values of the years, the highest NDVI values were acquired at 73.17% and 72.58% in 2013-14 and 2014-15, respectively in rainfed conditions, while it was obtained with 75.47% and 75.67%, in 2013-14 and 2014-15 years, respectively in irrigated conditions. When the NDVI values of the sowing densities were evaluated, the highest average NDVI values were obtained at 72.52% and 73.51% respectively from HSD and VHSD applications in rainfed conditions. In irrigated conditions, OSD, HSD, and VHSD applications stood out with 75.11%, 75.48 and 75.78% respectively. Considering the average NDVI values of genotypes, the highest values were obtained from Bezostaja1, Harmankaya-99, and Sultan 95 cultivars in both conditions. While 71.78, 72.97, and 72.34% values were obtained from these cultivars in rainfed conditions, respectively, 76.08, 75.42, and 75.47% values were obtained in irrigated conditions, respectively. When the effect of the environment on NDVI values was evaluated, the average NDVI value obtained from irrigated conditions was found to be 75.00%. This value was 4.5% higher than the average NDVI value of 71.76% in rainfed conditions. On the other hand, due to the instability of Harmankaya-99, Bezostaja1, and Sultan 95 cultivars in years, the interaction of Years x Genotypes was found statistically significant in both conditions. Years x Sowing Density interaction was significant only in rainfed conditions because of 2013-14 years SSD value stood out (Table 5).

Correlations between NDVI and Biomass Yield

A very high positive correlation was found between biomass yields of flowering and harvest period under rainfed and irrigated conditions (Table 6). This value was slightly higher in rainfed conditions (R = 0.837) compared to irrigated conditions (R = 0.786). In parallel with this, the correlation value between NDVI values and biomass yields in both the harvest and flowering period was found to be positive and significant too. Similarly, the correlation values between NDVI, FBY, and HBY values were higher in rainfed conditions (R = 0.645 and R = 0.659) compared to irrigated conditions (R = 0.313 and R = 0.359), respectively.

Table 4. Harvesting period biomass yield values (t ha^{-1}) and comparison of its means in both conditions
Çizelge 4. Hasat dönemi biyokütle verimi değerleri (t ha^{-1}) ve her iki koşulda ortalamaların karşılaştırılması

	Rainfed			
Treatment	2012-2013	2013-2014	2014-2015	Mean
Sowing Density				
SSD	5.17 ± 0.36 b	7.84 ± 0.27 b	10.26 ± 0.37 ab	7.76 ± 0.37 b
OSD	5.98 ± 0.51 b	8.09 ± 0.56 b	8.98 ± 0.50 b	7.67 ± 0.30 b
HSD	7.36 ± 0.63 a	9.21 ± 0.31 a	9.63 ± 0.36 ab	8.73 ± 0.30 a
VHSD	7.59 ± 0.68 a	8.62 ± 0.35 ab	10.73 ± 0.69 a	8.97 ± 0.35 a
LSD (0.05)				0.69**
Cultivars				
Alpu 2001	6.93 ± 0.68 ab	9.87 ± 0.48 a	10.24 ± 0.33 ab	9.01 ± 0.42 a
Atay-85	6.37 ± 1.34 bc	8.02 ± 0.24 b	8.94 ± 0.48 b	7.77 ± 0.39 b
Bezostaja1	6.07 ± 1.04 bc	7.82 ± 0.48 b	10.94 ± 0.84 a	8.26 ± 0.47 b
Harmankaya-99	7.59 ± 0.78 a	8.48 ± 0.60 b	10.85 ± 0.73 a	8.97 ± 0.43 a
Sönmez 2001	6.31 ± 0.56 bc	8.17 ± 0.39 b	9.30 ± 0.38 ab	7.92 ± 0.34 b
Sultan 95	5.88 ± 0.44 c	8.26 ± 0.36 b	9.14 ± 0.54 ab	7.77 ± 0.39 b
LSD (0.05)				0.60**
Means of years	6.52 ± 0.33 C	8.44 ± 0.21 B	9.90 ± 0.27 A	8.28**
CV (%)	18.97	17.09	22.55	21.71
	Irrigated			
Treatment	2012-13	2013-14	2014-15	Mean
Sowing Density				
SSD	9.75 ± 0.64 b	10.33 ± 0.57 b	11.85 ± 0.43 a	10.65 ± 0.31 b
OSD	11.06 ± 0.61 a	12.06 ± 0.47 a	11.35 ± 0.62 a	11.49 ± 0.30 a
HSD	10.89 ± 0.77 a	9.69 ± 0.32 b	11.63 ± 0.22 a	10.74 ± 0.27 b
VHSD	9.64 ± 0.59 b	10.14 ± 0.60 b	12.16 ± 0.68 a	10.65 ± 0.32 b
LSD (0.05)				0.65*
Cultivars				
Alpu 2001	11.10 ± 0.74 ab	12.40 ± 0.85 a	12.42 ± 0.39 a	11.97 ± 0.40 a
Atay-85	10.21 ± 0.30 b	10.64 ± 0.59 b	11.38 ± 0.69 a	10.74 ± 0.28 b
Bezostaja1	7.99 ± 0.45 c	9.74 ± 0.35 b	11.25 ± 0.18 a	9.66 ± 0.36 c
Harmankaya-99	12.07 ± 0.65 a	10.31 ± 0.74 b	11.86 ± 0.18 a	11.41 ± 0.37 ab
Sönmez 2001	10.41 ± 0.73 b	9.58 ± 0.74 b	12.43 ± 1.06 a	10.81 ± 0.37 b
Sultan 95	10.23 ± 0.54 b	10.68 ± 0.38 b	11.15 ± 0.72 a	10.69 ± 0.29 b
LSD (0.05)				0.82**
Means of years	10.34 ± 0.33 B	10.56 ± 0.30 B	11.75 ± 0.25 A	10.88**
CV (%)	14.4	14.94	17.05	15.69

* Significant at the 0.05 probability level; ** significant at the 0.01 probability level; ns: Not significant; LSD: Least significant difference; CV: Coefficient variation; SSD: Sparse sowing density; OSD: Ordinary sowing density; HSD: High sowing density; VHSD: Very High sowing density.

DISCUSSION

In this study, the effect of sowing density treatments on total biomass yield at flowering and harvest periods in bread wheat was found statistically significant under both rainfed and irrigated conditions. However, this effect varied depending on the condition. When the average values of the years in rainfed conditions were analyzed, it was determined that there was a linear and positive effect on the biomass yield with increasing sowing density. This result is compatible with the studies of some researchers (Sajjad et al., 2009; Hu et al., 2018; Özkan, 2020; Shah et al., 2020). The lower germination rate of seeds in rainfed conditions may be one of the reasons for this situation. In addition, it has been reported by many studies that high sowing density provides an advantage in weed control (Menegat & Nilsson, 2019; Aharon et al., 2021; Wu et al., 2021). In the region of Central Anatolia, it has traditionally been adopted to use higher sowing density in wheat farming, generally in rainfed conditions. On the other hand, Bhatta et al. (2017) have reported that the increase in sowing density did not have a significant effect. But, when it comes to irrigated conditions, the situation is different. The highest biomass yield was obtained from the OSD treatment in both flowering and harvesting periods.

Table 5. NDVI values (%) and comparison of its means in rainfed and irrigated conditions
Çizelge 5. NDVI değerleri (%) ve yağışa dayalı ve sulu koşullarda ortalamalarının karşılaştırılması

	Rainfed Conditions			
Treatment	2012-2013	2013-2014	2014-2015	Mean
Sowing density				
SSD	65.83 ± 0.85 c	72.78 ± 0.79 ab	70.83 ± 0.87 b	69.91 ± 0.85 c
OSD	69.46 ± 0.75 b	71.67 ± 0.93 b	71.83 ± 0.72 b	71.10 ± 0.51 b
HSD	70.83 ± 1.02 ab	73.89 ± 0.52 a	72.83 ± 0.95 ab	72.52 ± 0.49 a
VHSD	71.71 ± 0.93 a	74.33 ± 0.64 a	74.83 ± 0.77 a	73.51 ± 0.46 a
LSD (0.05)				1.08**
Cultivars				
Alpu 2001	69.31 ± 1.03 bc	73.83 ± 0.62 ab	70.83 ± 0.83 b	71.32 ± 0.72 bc
Atay-85	69.24 ± 1.77 bc	72.17 ± 0.74 b	71.25 ± 1.11 b	70.82 ± 0.77 c
Bezostaja1	67.28 ± 1.71 c	72.42 ± 1.24 b	75.67 ± 0.71 a	71.78 ± 1.24 abc
Harmankaya-99	72.42 ± 1.44 a	73.92 ± 1.36 ab	72.58 ± 1.55 b	72.97 ± 0.79 a
Sönmez 2001	69.75 ± 1.36 b	72.17 ± 1.09 b	72.00 ± 0.65 b	71.31 ± 0.65 bc
Sultan 95	68.83 ± 1.54 bc	74.50 ± 0.52 a	73.17 ± 0.63 ab	72.34 ± 0.92 ab
LSD(0.05)				1.46**
Means of years	69.46 ± 0.63 B	73.17 ± 0.41 A	72.58 ± 0.49 A	71.76**
CV (%)	3.97	3.29	4.60	3.92
	Irrigated Conditions			
Treatment	2012-2013	2013-2014	2014-2015	Mean
Sowing density				
SSD	72.06 ± 0.93 b	74.17 ± 0.92 b	74.72 ± 0.83 b	73.65 ± 0.56 b
OSD	74.11 ± 0.74 a	76.28 ± 0.62 a	74.94 ± 0.74 b	75.11 ± 0.44 a
HSD	74.67 ± 0.17 a	75.78 ± 1.04 a	76.00 ± 1.05 ab	75.48 ± 0.49 a
VHSD	74.67 ± 0.38 a	75.67 ± 1.00 ab	77.00 ± 0.71 a	75.78 ± 0.46 a
LSD (0.05)				0.87**
Cultivars				
Alpu 2001	73.67 ± 1.05 b	75.83 ± 0.42 bc	75.50 ± 1.06 b	75.00 ± 0.55 b
Atay-85	72.83 ± 1.27 b	74.50 ± 1.00 cd	72.42 ± 0.44 c	73.25 ± 0.57 c
Bezostaja1	73.75 ± 0.52 b	76.75 ± 0.83 ab	77.75 ± 0.71 a	76.08 ± 0.63 a
Harmankaya-99	75.42 ± 0.83 a	74.25 ± 1.25 cd	76.58 ± 0.25 ab	75.42 ± 0.54 ab
Sönmez 2001	74.25 ± 0.50 ab	73.67 ± 1.16 d	76.50 ± 0.93 ab	74.81 ± 0.60 b
Sultan 95	73.33 ± 1.04 b	77.83 ± 0.62 a	75.25 ± 0.69 b	75.47 ± 0.70 ab
LSD(0.05)				0.99**
Means of years	73.88 ± 0.37 B	75.47 ± 0.45 A	75.67 ± 0.44 A	75.00**
CV (%)	2.68	3.01	3.21	3.04

** significant at the 0.01 probability level; LSD: Least significant difference; CV: Coefficient variation; SSD: Sparse sowing density; OSD: Ordinary sowing density; HSD: High sowing density; VHSD: Very high sowing density

Table 6. Correlation coefficients and significance status of NDVI and biomass yield values
Çizelge 6. NDVI ile biyokütle verimleri arasındaki korelasyon katsayilari ve önemlilik durumu

	Irrigated Conditions			
	NDVI	FBY	HBY	
NDVI	1	0.313**	0.359**	NDVI
FBY	0.659**	1	0.786**	FBY
HBY	0.645**	0.837**	1	HBY
	NDVI	FBY	HBY	
	Rainfed Conditions			

** Significant at the 0.01 probability level; NDVI: Normalized difference vegetation index; FBY: Flowering period biomass yield; HBY: Harvest period biomass yield

The HSD and VHSD treatments caused a decrease in biomass yield. In other words, increasing sowing density had a parabolic effect. This result is consistent with the result of the study of Amanullah et al. (2010). In this case, the importance of optimum sowing density in the utilization of nutrients and light in the soil has emerged. Soomro et al. (2009) reported that the increase in sowing density caused a decrease in total weight per plant.

Biomass yields obtained in this study varied significantly between years. This was observed to be more evident, especially in the trials under rainfed conditions (Table 3, 4). The fact that the highest biomass yields were reached in 2014-15 when the highest rainfall was received, also supports this view. Kara & Akkaya (2009) found similar results to this study and reported that the amount of precipitation had a significant and positive effect on biomass in rainfed conditions. This can be explained by the fact that temperature and precipitation values can vary considerably from year to year in Central Anatolia (Table 1). In addition, it has been reported that the distribution of precipitation within the season significantly affects the biomass yield values, and drought, especially during the stem-elongation and heading periods, negatively affects the biomass yield (Öztürk, 2011). In this case, since water stress is less experienced in irrigated trials, it can be expected that the biomass yields of rainfed trials will show more variability compared to irrigated trials. Some researchers declared that higher biomass yields were obtained from irrigated trials than from rainfed trials (Önder, 2007; Savaşlı et al., 2012). In the study conducted by Önder (2007), it was reported that the biomass yield obtained from the irrigated trial was 37% higher than that obtained from the rainfed trial.

In the research, it was observed that the increase in sowing density had a linear and positive effect on NDVI values under both rainfed and irrigated conditions (Table 5). In the 2013-14 and 2014-15 crop years, NDVI values were higher than in 2012-13, when less rainfall was received. On the other hand, NDVI values were proportional to the amount of water received during the vegetation period. Consequently, NDVI values acquired from the irrigated trials were higher than rainfed trials. This result is consistent with the results obtained in many studies (Önder, 2007; Savaşlı et al., 2012; 2023; Morgounov et al., 2014). In recent years, NDVI has been widely used to monitor wheat growth and correlate it with grain and biomass yield (Morgounov et al., 2014, 2019). NDVI has a positive relationship with biomass yield (Gutiérrez-Rodríguez., 2004; Önder, 2007; Savaşlı et al., 2012; 2023; Trentin et al., 2021: Walsh et al., 2022). According to Babar et al.(2006), the best growth periods for the application of vegetation index in biomass production were heading and grain-filling periods. Many studies have indicated that NDVI values can be used for biomass estimation (Önder, 2007; Meng et al., 2013; Morgounov et al., 2014; Savaşlı et al., 2023).

When the results of correlation analysis were examined (Table 6), a significant positive correlation was found between the NDVI value and the biomass yield results obtained in both flowering and harvesting periods in both conditions (Table 1). However, the correlation between NDVI and biomass yield was stronger in rainfed conditions than in irrigated conditions (Table 6). In other words, the biomass yield obtained during the flowering period and the NDVI values achieved during the flowering period gave parallel results (Table 5). In this case, it was determined that NDVI values obtained during the flowering period can be used reliably in the estimation of biomass yield. The findings obtained in this study are similar to many studies on the same subject. Many researchers have found a strong positive correlation between NDVI values during the flowering period and biomass yields obtained during the harvest period and reported that the NDVI tool can be used safely in biomass yield estimation (Meng et al., 2013; Mourgunov et al., 2014; Trentin et al., 2021; Walsh et al., 2022; Savaşlı et al., 2023).

When we examine the reasons why the year x genotype interaction was significant, in 2012-13, the Harmankaya-99 cultivar stood out in both rainfed and irrigated conditions, while the Alpu 2001 variety stood out in 2013-14. In 2014-15, there was no difference between the cultivars in irrigated conditions, while only the Bezostaja1 cultivar lagged the other cultivars in rainfed conditions (Table 3). It is one of the expected results that the cultivars responded differently to precipitation, cultivation, and temperature conditions over the years (Savaşlı et al., 2023).

CONCLUSION

It has been observed that sowing density practices have a significant effect on biomass yields and NDVI values in both rainfed and irrigated conditions. As a result, it can be recommended to plant the cultivars by applying High Sowing Density in rainfed conditions and with Ordinary Sowing Density in irrigated conditions to achieve a high biomass yield. When it comes to the evaluation of cultivars, Alpu 2001 and Harmankaya-99 are recommended for getting a high biomass yield in both conditions. These cultivars can be used as parents for breeding studies to develop new cultivars with high biomass in the future. In addition, it has been seen that the NDVI values obtained during the flowering period have a strong correlation with flowering and harvesting period biomass yields. Consequently, it can be said that the Green Seeker Hand Sensor used to obtain NDVI values is a fast and more reliable tool for biomass yield estimation.

However, in the future, investigating the relationship between NDVI values at other growing stages of wheat (e.g. tillering, stem elongation, booting, or heading) and biomass yield may also be beneficial for breeding studies.

Acknowledgment

This research was supported by The Republic of Türkiye Ministry of Agriculture and Forestry, General Directorate of Agricultural Research and Policy, Transitional Zone Agricultural Research Institute, Eskişehir, Türkiye.

REFERENCES

Aharon, S., Fadida-Myers, A., Nashef, K., Ben-David, R., Lati, R. N., & Peleg, Z. (2021). Genetic improvement of wheat early vigor promotes weed competitiveness under the Mediterranean climate. *Plant Science, 303,* 110785. doi:10.1016/j.plantsci.2020.110785

Aisawi, K. A. B., Reynolds, M. P., Singh, R. P., & Foulkes, M. J. (2015). The physiological basis of the genetic progress in yield potential of CIMMYT spring wheat cultivars from 1966 to 2009. *Crop Science, 55*(4), 1749-1764. doi:10.2135/ cropsci2014.09.0601

Amanullah, Khan, A., Hussain, & Z., Jan, D. (2010). Performance of wheat cultivars sown at different seeding rates under drought-stress conditions. *Archives of Agronomy and Soil Science, 56*(1), 99-105. doi:10.1080/03650340.902897641

Anonymous. (2022). The world population is projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. Retrieved from https://www.un.org/en/desa/ world population-projected-reach-98-billion-2050-and-112 billion-2100

Atkinson Amorim, J. G., Schreiber, L. V., de Souza, M. R. Q., Negreiros, M., Susin, A., Bredemeier, C., ... & Parraga, A. (2022). Biomass estimation of spring wheat with machine learning methods using UAV-based multispectral imaging. *International Journal of Remote Sensing, 43*(13), 4758-4773.

Babar, M. A., Reynolds, M. P., Van Ginkel, M., Klatt, A. R., Raun, W. R., & Stone, M. L. (2006). Spectral reflectance to estimate genetic variation for in-season biomass, leaf chlorophyll, and canopy temperature in wheat. *Crop Science, 46*(3), 1046-1057. doi:10.2135/cropsci2005.0211

Bhatta, M., Eskridge, K. M., Rose, D. J., Santra, D. K., Baenziger, P. S., & Regassa, T. (2017). Seeding rate, genotype, and topdressed nitrogen effects on yield and agronomic characteristics of winter wheat. *Crop Science, 57*(2), 951-963. doi:10.2135/cropsci2016.02.0103

Cabrera-Bosquet, L., Molero, G., Stellacci, A., Bort, J., Nogués, S., & Araus, J. (2011). NDVI is a potential tool for predicting biomass, plant nitrogen content, and growth in wheat genotypes subjected to different water and nitrogen conditions. *Cereal Research Communications, 39*(1), 147-159.

Carr, P. M., Horsley, R. D., & Poland, W. W. (2003). Tillage and seeding rate effects on wheat cultivars: I. Grain production. *Crop Science, 43*(1), 202-209.

Chandel, N. S., Tiwari, P. S., Singh, K. P., Jat, D., Gaikwad, B. B., Tripathi, H., & Golhani, K. (2019). Yield prediction in wheat (Triticum aestivum L.) using spectral reflectance indices. *Curr. Sci, 116*(2), 272.

Dai, J., Bean, B., Brown, B., Bruening, W., Edwards, J., Flowers, M., …& Wiersma, J. (2016). Harvest index and straw yield of five classes of wheat. *Biomass and Bioenergy, 85,* 223-227. doi:10.1016/j.biombioe.2015.12.023

Foulkes, M. J., Snape, J. W., Shearman, V. J., Reynolds, M. P., Gaju, O., & Sylvester-Bradley, R. (2007). Genetic progress in yield potential in wheat: recent advances and prospects. *The Journal of Agricultural Science, 145*(1), 17-29. doi:10.1017/S0021859607006740

Foulkes, M. J., Slafer, G. A., Davies, W. J., Berry, P. M., Sylvester-Bradley, R., Martre, P., ... & Reynolds, M. P. (2011). Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance. *Journal of Experimental Botany, 62*(2), 469-486. doi:10.1093/jxb/erq300

Gündoğdu, K. S. (2018). Buğday ekili parsellerde NDVI değerlerinin konumsal ve zamana bağlı değişiminin belirlenmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 21*(4), 492-499.

Gutiérrez-Rodríguez, M., Reynolds, M. P., Escalante-Estrada, J. A., & Rodríguez-González, M. T. (2004). Association between canopy reflectance indices and yield and physiological traits in bread wheat under drought and well-irrigated conditions. *Australian Journal of Agricultural Research, 55*(11), 1139-1147. doi:10.1071/AR04214

Hu, C., Zheng, C., Sadras, V. O., Ding, M., Yang, X., & Zhang, S. (2018). Effect of straw mulch and seeding rate on the harvest index, yield, and water use efficiency of winter wheat. *Scientific reports, 8*(1), 1-8. doi:10.1038/s41598-018-26615-x

JMP. (2016). *JMP Users Guide, Version 13.0.0,* SAS Institute Inc., Cary, NC, USA.

Kara, R., & Akkaya, A. (2009). Kahramanmaraş yöresine ait yerel ekmeklik buğday genotiplerinin verim ve fizyolojik özellikler yönünden incelenmesi. *Türk Tarım ve Doğa Bilimleri Dergisi, 7*(4), 1186-1204.

Khan, A., Ahmad, A., Ali, W., Hussain, S., Ajayo, B. S., Raza, M. A., ...& Yang, W. (2020). Optimization of plant density and nitrogen regimes to mitigate lodging risk in wheat. *Agronomy Journal, 112*(4), 2535-2551. doi:10.1002/agj2.20211

Khan, T. S., & Mubeen, U. (2012). Wheat straw: A pragmatic overview. *Curr. Res. J. Biol. Sci, 4*(6), 673-675.

Lapidus, D., Salem, M. E., Beach, R. H., Zayed, S., & Ortiz-Monasterio, I. (2022). Greenhouse gas mitigation benefits and profitability of the GreenSeeker Handheld NDVI sensor: evidence from Mexico. *Precision Agriculture, 23*(6), 2388-2406.

Lovegrove, A., Pellny, T. K., Hassall, K. L., Plummer, A., Wood, A., Bellisai, A., ... & Shewry, P. R. (2020). Historical changes in the contents and compositions of fiber components and polar metabolites in white wheat flour. *Scientific reports, 10*(1), 1-9. doi:10.1038/s41598-020-62777-3

Ma, S. C., Wang, T. C., Guan, X. K., & Zhang, X. (2018). Effect of sowing time and seeding rate on yield components and water use efficiency of winter wheat by regulating the growth redundancy and physiological traits of root and shoot. *Field Crops Research, 221,* 166-174. doi:10.1016/j.fcr.2018.02.028

Menegat, A., & Nilsson, A. T. (2019). Interaction of preventive, cultural, and direct methods for integrated weed management in winter wheat. *Agronomy, 9*(9), 564.

Meng, J., Du, X., & Wu, B. (2013). Generation of high spatial and temporal resolution NDVI and its application in crop biomass estimation. *International Journal of Digital Earth, 6*(3), 203-218. doi:10.1080/17538947.2011.623189

Mitchell, P. L., & Sheehy, J. E. (2018). Potential yield of wheat in the United Kingdom: How to reach 20 t ha-1. *Field crops research, 224,* 115-125. doi:10.1016/j.fcr.2018.05.008

Molero, G., Joynson, R., Pinera-Chavez, F. J., Gardiner, L. J., Rivera-Amado, C., Hall, A., & Reynolds, M. P. (2019). Elucidating the genetic basis of biomass accumulation and radiation use efficiency in spring wheat and its role in yield potential. *Plant biotechnology journal, 17*(7), 1276-1288. doi:10.1111/pbi.13052

Morgounov, A., Gummadov, N., Belen, S., Kaya, Y., Keser, M., & Mursalova, J. (2014). Association of digital photo parameters and NDVI with winter wheat grain yield in variable environments. *Turkish journal of agriculture and forestry, 38*(5), 624-632. doi:10.3906/tar-1312-90

Morgounov, A. I., Ozdemir, F., Keser, M., Akin, B., Payne, T. S., & Braun, H. J. (2019). International Winter Wheat Improvement Program: history, activities, impact, and future. *Front. Agr. Sci. Eng. 2019, 6*(3), 240–250. doi:10.15302/J-FASE-2019261

Önder, O. (2007). Orta Anadolu kuru şartlarında yetiştirilen bazı ekmeklik buğday çeşitlerinin kardeşlenme dinamiğinin araştırılması (Tez No 179009). [Yüksek Lisans Tezi, Eskişehir Osmangazi Üniversitesi, Fen Bilimleri Enstitüsü Tarla Bitkileri Ana Bilim Dalı] Yükseköğretim Kurulu Ulusal Tez Merkezi

Özkan, M. (2020). Bingöl şartlarında farklı ekim sıklıklarında bazı ekmeklik buğday (Triticum aestivum. L) çeşitlerinin verim ve verim komponentlerinin belirlenmesi (Tez No 629037). [Yüksek Lisans Tezi, Bingöl Universitesi Fen Bilimleri Enstitüsü Tarla Bitkileri Ana Bilim Dalı] Yükseköğretim Kurulu Ulusal Tez Merkezi

Öztürk, İ. (2011). Ekmeklik buğday (Triticum aestivum L.) genotiplerinde kurağa dayanıklılığın karakterizasyonu ve kalite ile ilişkileri (Tez No 297713). [Doktora Tezi, Namık Kemal Üniversitesi Fen Bilimleri Enstitüsü Tarla Bitkileri Ana Bilim Dalı] Yükseköğretim Kurulu Ulusal Tez Merkezi

Ravindran, R., & Jaiswal, A. K. (2016). A comprehensive review on pre-treatment strategy for lignocellulosic food industry waste: challenges and opportunities. *Bioresource Technology, 199,* 92-102. doi:10.1016/j.biortech.2015.07.106

Reynolds, M., Foulkes, J., Furbank, R., Griffiths, S., King, J., Murchie, E., ...& Slafer, G. (2012). Achieving yield gains in wheat. *Plant, cell & environment, 35*(10), 1799-1823. doi:10.1111/j.1365-3040.2012.02588.x

Reynolds, M. P., Pask, A. J., Hoppitt, W. J., Sonder, K., Sukumaran, S., Molero, G., ... & Joshi, A. K. (2017). Strategic crossing of biomass and harvest index—source and sink—achieves genetic gains in wheat. *Euphytica, 213*(11), 1-23. doi:10.1007/s10681-017-2040-z

Reynolds, M., Chapman, S., Crespo-Herrera, L., Molero, G., Mondal, S., Pequeno, D. N., ... & Sukumaran, S. (2020). Breeder-friendly phenotyping. *Plant Science, 295,* 110396. doi:10.1016/j.plantsci.2019.110396

Reynolds, M. P., Slafer, G. A., Foulkes, J. M., Griffiths, S., Murchie, E. H., Carmo-Silva, E., ... & Flavell, R. B. (2022). A wiring diagram to integrate physiological traits of wheat yield potential. *Nature Food, 3*(5), 318-324.

Sajjad, M. R., Rashid, M., Akram, M., Ahmad, M. J., Hussain, R., & Razzaq, A. (2009). Optimum seed rate of wheat in available soil moisture under rainfed conditions. *Journal of Agricultural Research (03681157), 47*(2), 143-151.

Savaşlı, E., Çekiç, C., Önder, O., Dayıoğlu, R., Kalaycı, & H. M. (2012). Evaluation of Some Bread Wheat Cultivars and Advanced Breeding Lines for Yield, Biomass and Vegetation Index *International Journal of Agricultural and Natural Sciences, 5*(2), 33-37.

Savaşlı, E., Önder, O., Cekic, C., Kalaycı, H. M., Dayıoğlu, R., Karaduman, Y., ... & Gezgin, S. (2021a). Orta Anadolu Kuru Şartlarında Ekmeklik Buğdayda Optik Sensöre Dayalı Mevsim İçi Azotlu

Gübre *Kalibrasyon Optimizasyonu. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 24*(1), 130-140.

Savaşlı, E., Önder, O., Dayıoğlu, R., Özen, D., Karaduman Y., Özdemir, S., ... & Özsayın, M. (2021b). Ekmeklik Buğdayda Optik Sensör ile Azotlu Gübre Tavsiyesi. *Yuzuncu Yıl University Journal of Agricultural Sciences, 31*(2), 453-465.

Savaşlı, E., Önder, O., Dayıoğlu, R., Belen, S., Çakmak, M., Çekiç, C., ... & Erşahin, S. (2023). Estimating grain and biomass yield of bread wheat genotypes by optical sensors. *European Journal of Agronomy, 150,* 126923.

Shah, F., Coulter, J. A., Ye, C., & Wu, W. (2020). Yield penalty due to delayed sowing of winter wheat and the mitigatory role of increased seeding rate. *European Journal of Agronomy, 119,* 126120.

Shewry, P. R. (2009). Wheat. *Journal of experimental botany, 60*(6), 1537-1553.

Soomro, U. A., Rahman, M. U., Odhano, E. A., Gul, S., & Tareen, A. Q. (2009). Effects of sowing method and seed rate on growth and yield of wheat (Triticum aestivum). *World Journal of Agricultural Sciences, 5*(2), 159-162.

Student, (1908). The probable error of a mean. *Biometrika, 1-25.*

Townsend, T. J., Sparkes, D. L., Ramsden, J., Glithero N. J., & Wilson, P. (2018). Wheat straw availability for bioenergy in England. *Energy policy, 122,* 349-357. doi:10.1016/j.enpol.2018.07.053

Trentin, C., Bredemeier, C., Vian, A. L., Drum, M. A., & Santos, F. L. D. (2021). Biomass production and wheat grain yield and its relationship with NDVI as a function of nitrogen availability. *Revista Brasileira de Ciências Agrárias (Agrária), 16*(4), e34, 1-7 p.

Walsh, O. S., Marshall, J., Jackson, C., Nambi, E., Shafian, S., Jayawardena, D. M., ... & McClintick-Chess, J. R. (2022). Wheat yield and protein estimation with handheld and UAV-based reflectance measurements. *Agrosystems, Geosciences & Environment, 5*(4), e20309.

Walter, J. D., Edwards, J., McDonald, G., & Kuchel, H. (2019). Estimating biomass and canopy height with LiDAR for field crop breeding. *Frontiers in plant science, 10,* 1145.

Wu, Yue, Nianxun Xi, Jacob Weiner, and Da-Yong Zhang. (2021). Differences in weed suppression between two modern and two old wheat cultivars at different sowing densities. *Agronomy 2021, 11*(2), 253. doi:10.3390/agronomy11020253

Zadoks, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Research, 14*(6), 415-421.

Zecha, C. W., Peteinatos, G. G., Link, J., & Claupein, W. (2018). Utilization of ground and airborne optical sensors for nitrogen level identification and yield prediction in wheat. *Agriculture, 8*(6), 79.