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Use of plant indices in early yield estimation for winter wheat

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Abstract: The study was carried out in İkizce Research Farm of Field Crops Central Research Institute in 2014 and 2015 . The experiment was established according to random blocks experimental design with three replicates and 0, 4, 8, 12 and 16 kg/da nitrogen applications were made. Normalized difference vegetation index (NDVI) readings were taken with a portable handheld GreenSeeker device throughout the growing season. Spectroradiometer readings were taken in each plot from sowing to harvest. In addition, the relationships between biophysical characteristics of the plant and yield values were determined. The measured spectroradiometer values were used to calculate various plant indices reported in the literature. Considering the phenological development periods between 2013 and 2014 in Haymana, the correlation values between grain yield and spectral indices (r^2 <0,277) in the early period (Feekes 1-9) from emergence to stalk emergence were lower than the values (r^2 <0,603) in the late period (Feekes 10-11,4). The correlation values of the first ten indices (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) in the late development period (flowering) ranged between R^2=0.453-0.603 and Green + Red + Red Border + Near Infra-Red (NIR) bands were prominent. The highest correlations between grain yield and spectral indices were determined at the beginning of flowering (26 May 2015) and correlation values ranged between R^2= 0.930-0.889 for the first ten indices for 2014-2015 growing season. The prominent indices in this period were NVI, SR-8, SR-11, SR-5, SR-17, OVI, SR-2, SR-1, ZTM, SR-16, respectively. These indices were in located in the 550-900 nm band range, in the green+red+red+red edge (Red Edge) + Near Infrared (NIR) range on the electromagnetic spectrum. The use of spectral data in early yield estimation in wheat is important in terms of guiding national agricultural policies. The application and dissemination of this estimation method in yield estimations in different locations in the future will provide great convenience.

Keywords: Wheat, indice, estimation, spectral reflectance, yield.

Kışlık buğday için erken dönem verim tahmininde bitki indekslerinin kullanımı

Öz: Çalışma 2014 ve 2015 yıllarında Tarla Bitkileri Merkez Araştırma Enstitüsü İkizce Araştırma Çiftliğinde yürütülmüştür. Deneme tesadüfi bloklar deneme desenine göre kurulmuş, üç tekerrürlü olmak üzere, 0, 4, 8, 12 ve 16 kg/da azot uygulamaları yapılmıştır. Bitki yetişme dönemi boyunca taşınabilir el GreenSeeker cihazı ile NDVI okumaları yapılmıştır. Her parselde ekimden hasada kadar gelişme peryodu boyunca spektroradyometre okumaları yapılmış, bunun yanısıra bitkinin biyofiziksel özellikleri ile verim değerleri arasındaki ilişkiler belirlenmiştir. Ölçülen spektroradyometre yansıma değerlerinden faydalanılarak literatürde verilen çeşitli bitki indeksleri hesaplanmıştır. Haymanada 2013 -2014 yılları arasında fenolojik gelişme dönemleri gözönüne alındığında çıkıştan sapa kalkmaya kadar olan erken dönemde (Feekes 1-9), dane verimi ile spektral indeksler arasındaki korelasyon değerleri (r <0,277), çiçeklenmeden danenin sararmasına kadar devam eden geç dönemdeki (Feekes 10-11,4) korelasyon değerlerine göre (r <0,603) düşük seyretmiştir. Geç gelişme döneminde (Çiçeklenme) öne çıkan ilk on indeksin (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) korelasyon değerleri R^2=0,453-0,603 arasında değişmiş ve Yeşil+Kırmızı+Kırmızı Sınır+Yakın Kızıl Ötesi bandlar ön plana çıkmıştır. 2014-2015 gelişme döneminde dane verimi ile spektral indeksler arasındaki korelasyonların en yüksek olduğu dönem çiçeklenme başlangıcı (26 Mayıs 2015) olarak belirlenmiş, korelasyon değerleri ilk on indeks için r= 0.930-0.889 arasında değişmiştir. Bu dönemde öne çıkan indeksler sırasıyla NVI, SR-8, SR-11, SR-5, SR-17, OVI, SR-2, SR-1, ZTM, SR-16 şeklinde sıralanmıştır. Bu indeksler 550-900 nm bant aralığında, elektromanyetik spektrum üzerinde yeşil+kırmızı+kırmızı sınır (Red Edge) +Yakın Kızıl Ötesi (NIR) aralıkta yer almıştır. Spektral verilerin buğday 'da erken dönemde verim tahmininde kullanımı ülkesel tarımsal politikalara yön vermesi açısından önemlidir. Bu bakımdan gelecekte farklı lokasyonlarda rekolte tahminlerinde bu tahmin yönteminin uygulanması ve yaygınlaştırılması büyük kolaylıklar sağlayacaktır.

Anahtar kelimeler: Buğday, indeks, tahmin, spektral yansıma, verim.

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1. Introduction

The impact of the plant's environment and its growth may be assessed by vegetation indices, regardless of the growing environment. Plant water requirement, fertilization, climate and soil properties significantly alter the yield of crop plants. Crop simulation models mimic these inputs to estimate the expected yield in yield estimation for a specific region.Vegetation indices can determine the response of the plant to the environment without considering the complex relationships in plant growth. Normalised vegetation difference index (NDVI) is a widely used vegetation index. It was developed by Deering (1978). NDVI is related to the amount of nitrogen in the plant, chlorophyll content and green biomass. Plants absorb red (RED) wavelength light and use it for photosynthesis, so they reflect less in this region, while they reflect more near infrared (NIR) wavelength light. NDVI is calculated from the ratio of these two wavelength reflectance differences to their sum, i.e., NDVI = (NIR-RED) / (NIR+RED). Several studies have shown high correlations between vegetation indices derived from spectral observations and standard plant traits such as plant height, coverage and planting density number (Raun et al., 2005 and Stone et al., 1996). Vegetation indices are widely used in agriculture, because they allow fast and efficient detection of vegetation change and are easy to apply (Cattani et al., 2017). Studies have shown that plants show the most typical reflection in the NIR region (400-1100 nm). Therefore, spectro radiometric measurements in plants are concentrated in the NIR region (Başyiğit and Dinç, 2001).

Vegetation indices help to reveal the spectral reflectance characteristics of plants more clearly on green vegetation and help to eliminate negative effects caused by soil and other factors (Huete et al. 1985; Major et al. 1990). Spectral reflectance values provide a correlation between plant health and leaf biochemical concentration (Curran, 1989). Spectral indices can be measured on a single leaf of the plant or on a canopy. Values obtained from single leaf measurements neglect the influence of environmental conditions to a greater extent, while canopy measurements give larger scale values. Leaf-scale trials are rather used to obtain information on the chlorophyll concentration of whole branches from the biochemical concentration of the leaf from cellular reflections in plant tissues (Carter and Spiering, 2002). Gamon (1992) concluded that the use of multi-band indices is necessary to observe changes in plants rich in pigments such as carotenoids. These normalised index values are effectively used to reveal the biophysical parameters of plants using the spectral bands of vegetation (red and near infrared).

Reflectance values in the RED band range are inversely related to the amount of chlorophyll in plants, while reflectance values in the NIR infrared band range are directly related to leaf area (Tucker 1979). Spectral indices have been widely used in many agricultural applications to compare different growth patterns at field, regional and global scales (Elvidge and Chen, 1995). Geographical information systems are integrated with remote sensing technology to estimate bio-physical data and to measure plant biomass (Aparicio, et al., 2000). Raun et al. (2001), estimated the potential yield of winter wheat by spectral measurements after dormancy and to determine the relationship between the estimated yield and the actual yield in nine locations. The results indicated that there was a significant relationship between the yield calculated from the readings made at Feekes 4-5 (ZD 31) and the actual yield at the level of (r = 0.50**). Spectral vegetation index (NDVI) measurements made in wheat in the early period can help to calculate the differences in the light utilization capacity of genotypes as well as differences in their biomass can be calculated. This value (NDVI) also gives an idea about the photosynthetic capacity in relation to the total chlorophyll content in the biomass (Gutierrez-Rodriguez et al. 2004). Another environmental factor determining plant yield is cumulative temperature. The correlation between phenologically calculated growing degree days GDD and NDVI (Normalised Difference Vegetation Index) data during the growing season is very high (Karlsen et al., 2005). Raun et al. (2001), found that spectral measurements (NDVI) at different growth stages of winter wheat have a very significant relationship with total biomass in determining yield potential. Vegetation indices have been used to increase crop production and reduce the environmental burden of agriculture. Easy-to-use and effective measuring devices have been developed for vegetation index measurement, especially for nitrogen fertilizer applications. Nitrogen is the limiting nutrient for crop production and has the greatest impact on grain. Five different nitrogen doses (0, 4, 8, 12, 16 kg/da) were applied in three replicates according to the coincidence blocks experimental design. In each plot, spectroradiometer readings were taken throughout the growth period from sowing to harvest, and the relationships between biophysical characteristics of the plant and yield values were determined. The measured spectroradiometer values were used to calculate various plant indices reported in the literature. The correlations of these indices values with yield and other biophysical parameters were examined, and the behavior of these indices in different phenological development periods (early-late-all) and fertilizer doses were investigated. In conclusion, the main objective of this study was to investigate the usefulness of hyperspectral data for early yield prediction in winter wheat and to determine which plant indices and which band regions are effective for this purpose.

2. Material and Method

2.1. Plant material

The project was carried out in the production farm of the Central Research Institute of Field Crops in İkizce, Haymana district of Ankara in 2013-2014 and 2014-2015 growing seasons. İkizce winter wheat cultivar was used in the study. The experiment was established according to random blocks experimental design and five different nitrogen doses, i.e., 0, 4, 8, 12 and 16 kg N/da were used with three replications. Biophysical observations and NDVI readings were taken seven times during the growing period of both years. A portable GreenSeeker device was used to follow the vegetation development of the plant in the field.

2.2. Climate and soil characteristics of the experimental site

The farm has been established in the south-west of Ankara where continental climate prevails, with dry and hot summers and cold and rainy winters. The experiment was carried out in İkizce/Haymana Research and Application Farm of the Central Research Institute of Field Crops (Figure 1). The test area is between 39‘ 12’’ -43’ 6’’ north latitude and 35‘ 58’’ -37’ 44’’ east longitude.

Figure 1. Haymana-İkizce production enterprise and experiment area.

2.3. Climatic characteristics of the research site

The average annual temperature of the area is 10.0 ºC according to the 20-year data of İkizce station. The average highest temperature is 18.5 °C in August and the average lowest temperature is -5.2 °C in January. Total annual rainfall totals is 398.7 mm. The wettest month is December with 53.8 mm and the driest month is August with 13.8 mm. precipitation.

2.4. Soil characteristics of the research site

The soil of İkizce farmlands belong to the brown soil group. The soil texture is generally medium heavy and the lime content in the soil is high (25-45 %). The amount of organic matter in the soil is approximately 1 % and pH is around 7,5. The slope of the land varies between 2-15%. The altitude of the area where the meteorological station is located in the farm is 1070 m.

2.5. Experimental design

The experiment was started in Haymana with the preliminary trial results obtained in 2012-2013 for the first year. Afterwards, it was continued with the data collected on the experimental plots established in Haymana during 2013-2014 and 2014-2015. The experiment was carried out by applying different nitrogen doses to each plot on the plots formed according to the random blocks experimental design with three replications. Five different 0-4-8-12-16 kg/da pure nitrogen doses were used in each replicate. The experimental area consists of a total of 15 plots (3.15 m x 10 m = 31.5 m^2). Twenty (20) kg seeds of

İkizce wheat variety per decare was sown with 24-row pneumatic seeder keeping row spacing of 13 cm. Half of the plot length determined for each plot was reserved for agronomic sampling (% cover, LAI calculation, wet-dry biological mass per m^2, etc.). The remaining half (5 m) was allocated for the calculation of grain yield. For the collection of biomass data, 0.25 m^2 quadrate (0.50m x 0.50m) was used. Plant samples in the quadrate were were harvested, weighed fresh and then dried in an oven at 70-80 ^oC for 3-4 days and calculated as kg/ha.

2.6. Fertilization and sampling dates

In the experiment, 5.5 kg P_2O_5/da (DAP 18-46%) and 12 kg/ha DAP base fertilizer was applied to the soil before sowing and 0.378 kg/ 31.5 m^2 DAP fertilizer was applied for each plot. Ammonium nitrate (33%) nitrogen fertilizer (0-0.176-0.557-0.557-0.939-1.321-1.321- kg/31.5 m^2) was applied in addition to the plots for 5 different nitrogen doses (0-4-8-12-16 kg/da) in the experiment established with three replicates as top dressing in early spring. Fertilizer applications were applied by subtracting nitrogen provided by DAP. All phosphorus was applied at planting, whereas half of the nitrogen was applied at planting, and the remaining half was applied as top dressing at the end of the tillering period in spring. Sampling times of 2013-2014 and 2014-2015 were determined according to phenological periods (Table 1, 2).

Table 1. Number and dates of sampling according to different growth stages (Zadoks) in Haymanada during 2013-2014 vegetation period.

Phenological Period (2013-2014) Date	Cultivar	Sampling Periods *(Feekes)*	Number of Samples	Zadoks Scale
19 March2014	İkizce	Emergence (1)	6	10-19
26 March 2014	İkizce	Tillering (2)	16	21-25
3 April 2014	İkizce	End of Tillering (3)	15	26-29
22 April 2014	İkizce	Beginning of Jointing (4-5)	15	30
13 May 2014	İkizce	Jointing (6-7)	15	31-39
22 May 2014	İkizce	Emergence of the Flag Leaf (8-9)	16	40-69
26 May 2014	İkizce	Beginning of flowering (10)	16	
4 June 2014	İkizce	Beginning of the Milk Period (11)	16	70-77
12 June 2014	İkizce	Dough Formation Period of Grain, (11.2)	16	80-87
24 June 2014	İkizce	Hardening, ripening and yellowing of the grain (11.3-11.4)	16	91-92
		Total Number of Samples	147	

Table 2. Number and dates of sampling according to different growth stages (Zadoks) in Haymanada during 2014-2015 vegetation period.

Phenological Period (2014-2015) Date	Cultivar	Sampling Periods (Feekes)	Number of Samples	Zadoks Scala
18 March 2015	İkizce	Emergence ((1-2)	-	10-19
06 April 2015	ikizce	End of Tillering (3)	16	26-29
17 April 2015	İkizce	Beginning of Jointing (4-5)	16-	30
30 April 2015	İkizce	Jointing (5)	16	26-29
12 May 2015	İkizce	Jointing (6-7)	16	31-39
26 May 2015	İkizce	Beginning of flowering (8-10)	16	40-69
10 June 2015	İkizce	Beginning of the Milk Period (11)	16	70-77
07 July 2015	İkizce	Hardening, ripening and yellowing of the grain (11.3-11.4)	16	80-92
		Total Number of Samples	128	

2.7. Collection and evaluation of hayperspectral data

Spectroradiometric canopy reflectance measurements were made using a portable handheld spectroradiometer between 11 am and 15 pm, when the sun's rays were perpendicular to the earth's surface and cloudless. Spectral reflections in the plant leaves were carried out with the help of the spectral sensor band range from 350 nm to 1150 nm every 3 nm. The measurements were instantly transferred to the computer with cable connection. Measurements were taken from a height of 70 cm at an angle of 25^0 ' to the earth's surface.

Measurements were taken at 8 different phenological periods. These measurements were then averaged and used in the calculation. Using the reflection values, the vegetation index values given in the appendix were calculated and their correlation with yield was revealed (Table 3).

Table 3. Indices used in yield estimation in the project

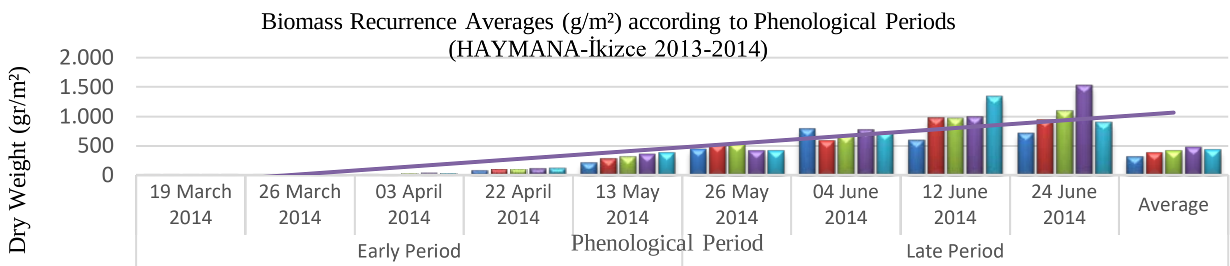
Structural Indices		Chlorophyll Pigment Indices		Red Edge Indices
SR1	NDVI13	NDI5	SRPI (Simple Ratio Pigment Index)	Red Edge 750~700
SR2	NDVI14	NDI9	RVI (Ratio Vegetation Index)	Red Edge 740~ 720
SR4	NDVI16	NDVI1	RDVI (Renormalized Difference Vegetation Index)	ZTM (Zarco Tejada and Miller)
SR5	NDVI17	NDVI2	MCARI2	
SR7	NDVI18	NDVI3	TVI (Triangular vegetation Index)	
SR5	NDVI(Modis)	NDVI4	LCCI (Leaf and Canopy Chlorophyll Index)	
SR8	HNDVI	NDVI5	NVI (New Vegetation Index)	
SR9	SR11	NDVI6	DVI (Difference Vegetation index)	
SR10	SR14	NDVI11	OVI (Optimum Vegetation İndex)	
SR11	SR16	NDVI12	HVI	
SR14	SR17	NDVI13	NVI	
SR16	MTVI	NDVI14	ARI	
NDVI	SR17	NDVI16	NPCI	
NDI1	SAVI (Soil Adjusted Veg. Index)	NDVI17	ARI	
NDI2	MSAVI	NDVI18	SIPI (Structural insensitive Pigment index)	
NDI3	OSAVI (Optimized SAVI)		GREEN INDEKS	
NDI4	TCI/OSAVI		PSRI	
NDI9	MSR		PRI	
NDI10	SR8		PhRI	

3. Results and Discussion

3.1. Relationship between yield (biological yield) and spectral indices

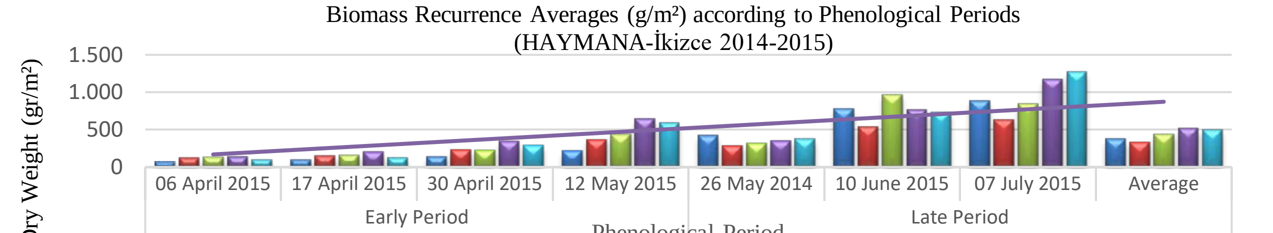
Analysis of biomass variation over the plant growth period (Haymana 2013-2014) revealed that biomass increased from the early to the late period in correlation with the increasing nitrogen dose. The highest amount of biomass (1538.51 g/m^2) was observed at 12 kg/da N dose in the late period (Figure 2). In the 2014-2015 growth period, the highest biomass was noted for 16 kg/da N dose in the late period (1277.87 g/m^2) (Figure 3).

Correlation (r) analysis between wheat biomass (ton/da) and single band reflectance values (at 3 nm wavelength) during the 2013-2014 growth periods revealed significant correlation between biomass and wavelengths within the 409-549 nm range in the visible spectrum (Feekes 4-7) and in the red edge region (700-770 nm), particularly during the early, late, and overall growth phases. During the late period (Feekes 8-10), an increased correlation was noted in the wavelength range of 530-680 nm within the visible spectrum. Conversely, a negative change in correlation was recorded in the red edge region (700-750 nm), while non-significant correlation was observed in the near-infrared region (750-1000 nm). Throughout the whole duration (Feekes 4-10), the most significant change in correlation was seen in the red edge spectrum (Red Edge 700-750 nm) (Figure 4).



	19 March 2014	26 March 2014	03 April 2014	22 April 2014	13 May 2014	26 May 2014	04 June 2014	12 June 2014	24 June 2014	Average
0	6.733	9.73	14.05	76.32	209.31	447.04	787.47	602.88	723.15	319.631
4	5.02	10.61	23.73	98.45	284.91	520.43	594.99	977.97	947.04	384.794
8	8.01	14.16	26.43	98.37	319.2	524.8	672.16	974.08	1097.07	414.92
12	5.82	19.41	34.51	112.21	357.07	417.12	771.95	998.93	1538.51	472.837
16	11.367	23.52	26.69	117.39	381.55	419.89	731.09	1342.4	904.32	439.802

Figure 2. Variation in biomass of wheat according to the amount of nitrogen applied and phenological development period in 2013-2014 (gr / m^2).



	06 April 2015	17 April 2015	30 April 2015	12 May 2015	26 May 2014	10 June 2015	07 July 2015	Average
0	72.45	101.17	146.51	224.65	429.65	781.60	891.31	378.191
4	126.02	155.68	238.45	370.35	284.91	543.15	637.65	336.6
8	138.93	166.35	229.23	445.28	319.2	966.51	849.87	445.05
12	146.11	205.33	350.24	648.43	357.07	771.95	1172.96	521.73
16	99.63	131.95	294.13	590.35	381.55	731.09	1277.87	500.94

Figure 3. Variation in biomass of wheat according to the amount of nitrogen applied and phenological development period in 2014-2015 (gr / m^2)

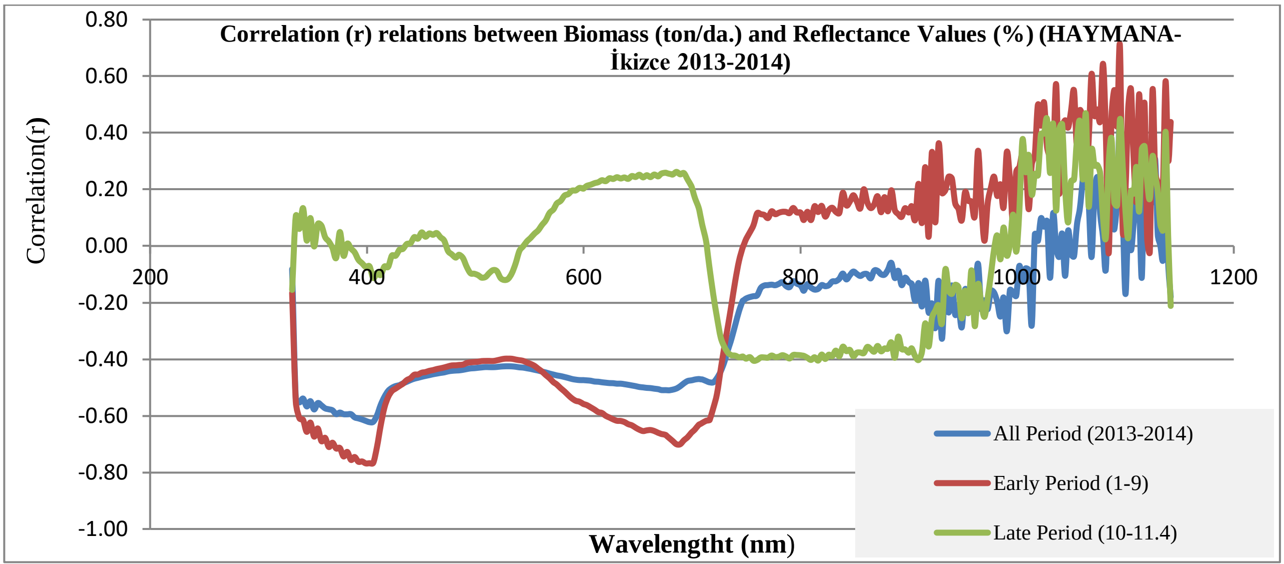


Figure 4. The correlation (r) relations between Biomass (ton/da) and single band reflectance values (3 nm) in wheat in 2013-2014.

3.2. Relationships between grainyield and spectral indices (2013-2014)

Relationships between grain yield-spectral indices for different phenological periods in Haymana 2013-2014 period indicated the highest correlation for flowering period (26 May 2014), stalk emergence period (13 May 2014) and milking period (04 June 2014), respectively. The prominent indices in these periods are SR-5 (650-700), SR-8 (550-860), NDVI-6 (708-760), NDVI-2 (700-800), Red Edge (720-740), SR-4 (720-740), LCCI (705-750). Green+Red+Red Edge+Near Infrared (NIR) bands have come to the fore to be used in yield estimation (Table 4). Considering the phenological development periods, the correlation values (r= 0.277) between grain yield and spectral indices in the early period from emergence to stalk emergence (Feekes 1-9) were lower than the correlation values (r = 0.603) in the late period from flowering to yellowing of grain (Feekes 10-11,4). The correlation values of the first ten indices (SR-5, SR-8, NDI-2, OVI, SR-2, SR-17, NDVI-3, SR-10, NDI-1, NVI) which were prominent in the late development period (Stalk emergence+Blooming+Milk maturity+Grain setting) varied between r =0.453-0.603 and Green + Red+ Red border + NIR bands were prominent. Correlations in the late period were found to be higher than in the other periods.

The correlation between grain yield and spectral indicators across several phenological phases revealed the strongest correlation values during the flowering period on 26 May 2014 (Figure 5).

Table 4. Grain yield-index relationships according to different development periods (Early-Late-All Periods) (Haymana-2013-2014).

Early Period		Late Period		All Period	
Indices	*r*	*Indices*	*r*	*Indices*	*r*
Red Edge (740-720)	0.277	SR-5	0.603	SR-8	0.348
SR-4	0.277	SR-8	0.581	SR-5	0.347
SR-9	0.255	NDI-2	0.571	Red Edge (740-720)	0.325
ZTM	0.254	OVI	0.507	SR-4	0.325
SR-16	0.252	SR-2	0.494	NVI	0.320
SR-5	0.242	SR-17	0.483	ZTM	0.313
TVI	0.239	NDVI3	0.464	OVI	0.311
Red Edge (750-700)	0.237	SR-10	0.461	SR-16	0.308
HVI	0.237	NDI-1	0.460	SR-9	0.303
SR-8	0.236	NVI	0.453	SR-17	0.281

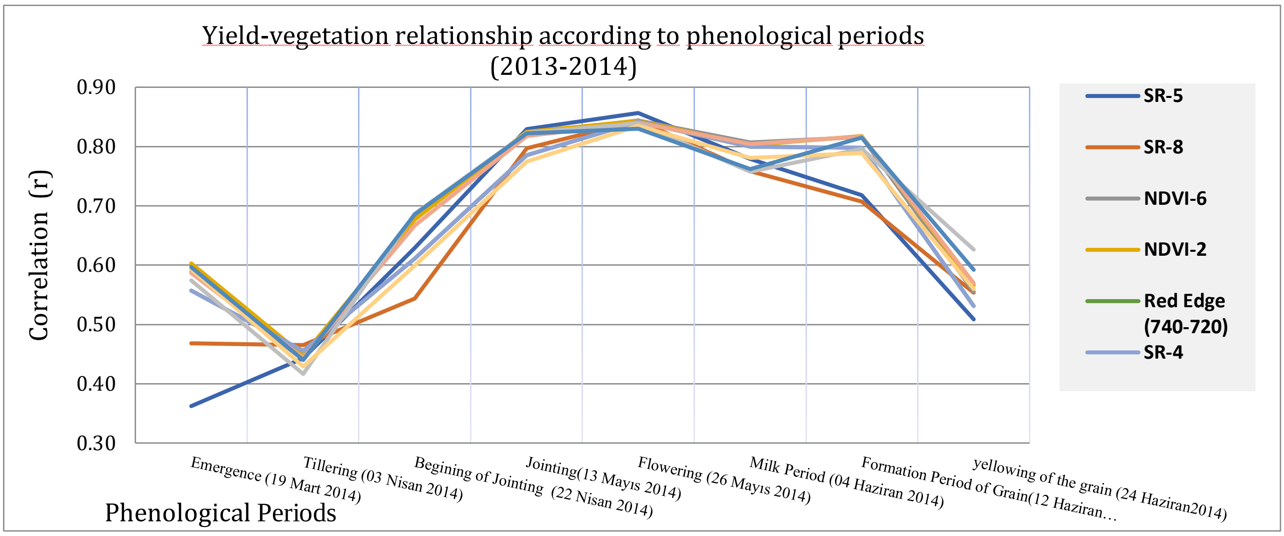


Figure 5. Fenolojik dönemlere göre verim-vejetasyon indeks ilişkisi (2013-2014).
SR-5 (650-700 nm.) Red+Red Edge, SR-8 (550-860 nm.) Green+Red+Near Infrared, NDVI-6 (708-760 nm.) Red Edge, NDVI-2 (700-800 nm.) Red Edge+ Near Infrared, Red Edge (740-720 nm.) Red Edge

The correlation values between the top ten prominent indices in this period ranged between r = 0.857-0.835. The prominent indices during this period were SR-5 (650-700), SR-8 (550-860), NDVI-6 (708-760), NDVI-2 (700-800), NDI-1 (715-747), Red Edge (740-720), SR-4 (740-720), LCCI (750-705), NDVI-3 (780-550) and ZTM (750-710). Effective spectral band regions for yield estimation were found to be Red+Red Edge (Red Edge)+Near Infrared (NIR). This period was followed by the Staggering period (13 May 2014), and the correlation values of the top ten indices in this period ranged between r = 0.849-0.813. The prominent indices in this period are NDI-2, NDI-1, SR-5, NDVI-2, NDVI-3, NDVI-6, NDVI-4, OSAVI, SIPI, NDVI(Modis), NDVI, SAVI. The correlation values between the first nine prominent indices during the Hardening Period (12 June 2014) ranged between r = 0.847-0.791. The prominent indices in this period were MSAVI, SAVI-1, NDVI-5, NDVI-2, NDVI-6, NDVI-4, RDVI, NDVI-3, OVI, NDVI-1. The correlation values between the top ten indices during the milking period (04 June 2014) ranged between r = 0.796-0.886. The prominent indices in this period were SRPI, OVI-1, NDI-2, NDVI-6, NDI-1, LCC, NDVI-2, Red Edge (740-720), SR-4, SR-14.

3.3. Relationships between yield and spectral indices (Haymana 2014-2015)

Correlation (between biomass (ton/da) and single band reflectance values (at 3 nm wavelength) indicated an increasing correlation in 530-680 nm band range. A negative decrease in the correlation was noted in the red region (Red Edge 700-750 nm), and no significant change in correlation was observed in NIR region (Figure 6). Considering different phenological periods, the highest biological yield values were found in the late period (10 June 2015) at 12 kg/da nitrogen dose. High correlation values were found in the blue band (400-500 nm.) green and red bands (570-680 nm.). High correlation values were found in the green and red band range (570-680 nm) in the early period (06 April-12 May 2015).

3.4. Relationships between grainyield and spectral indices (2014-2015)

Correlations between grain yield and spectral indices for different phenological periods during 2014-2015 indicated the highest correlation during the flowering period (26 May 2015), milking period (10 June 2015), stalk emergence period (12 May 2015), respectively (Table 5). The prominent indices in these periods were NVI(673-777), SR-8(550-860), SR-11(680-900), SR-5(650-700), SR-17 (560-810), OVI(730-760), SR-2(550-800), SR-1(670-801), ZTM(710-750), SR-16(705-750). Green + Red + Red Edge + NIR bands have come to the fore for use in yield estimation (Figure 10). Relationships between grain yield-spectral indices according to different phenological periods indicated the highest correlation during flowering period (26 May 2015) (Figure 7).

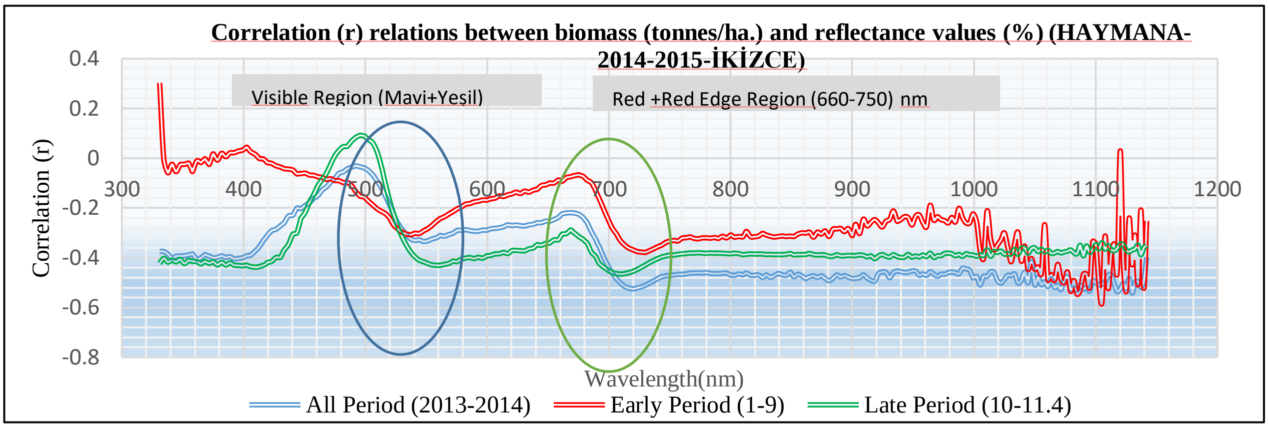


Figure 6. Correlation (r) relations between biomass (ton/da) and single band Reflectance Values (3 nm wave Saturation) in wheat (Haymana-2014-2015-İkizce).

Table 5. Correlations between grain yield and spectral indices and prominent indices during flowering period (Haymana 2014-2015).

Agronomic Properties	Indices	Band Range (nm.)	Correlation (r)	Determination Coefficient (R^2)	Regression Equation (26 May 2015)
Yield (kg/da)	NVI	673-777	0.964	0.930	Y= 0.0048X-0.4588
	SR-8	550-860	0.956	0.914	Y = 0.0015X- 0.0864
	SR-11	680-900	0.952	0.907	Y = 0.0305X + 0.1288
	SR-5	650-700	0.951	0.905	Y = 0.0002x + 0.0136
	SR-17	560-810	0.947	0.898	Y = 0.0199X + 0.4413
	OVI	730-760	0.946	0.895	y = 0.0017x + 0.9336
	SR-2	550-800	0.945	0.894	y = 0.0203x + 0.4963
	SR-1	670-801	0.945	0.893	Y= 0.0393x - 0.5
	ZTM	710-750	0.944	0.891	Y = 0.008x + 0.6097
	SR-16	705-750	0.943	0.889	Y = 0.0107x + 0.4741

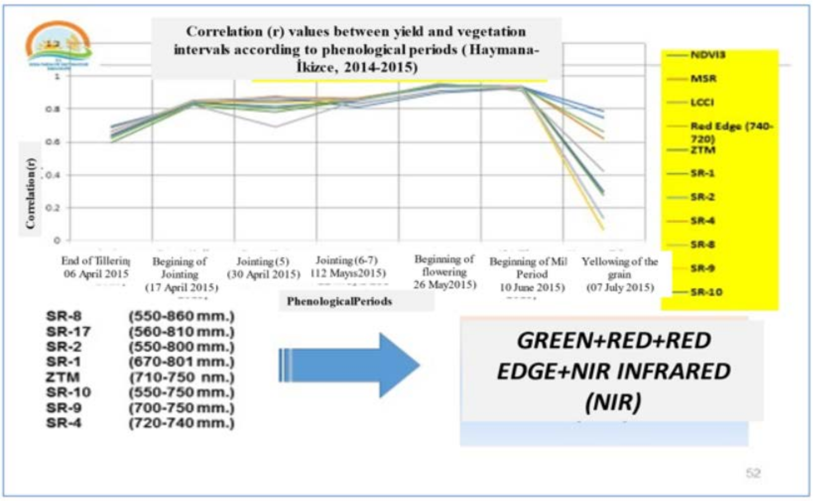


Figure 7. Yield-vegetation index relationship according to phenological periods (2014-2015)

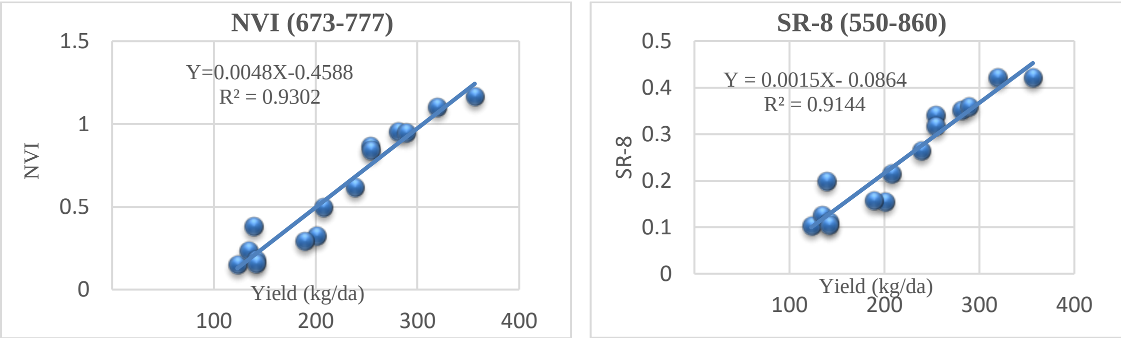


Figure 8. Spectral indices for predicting grain yield (2014-2015)

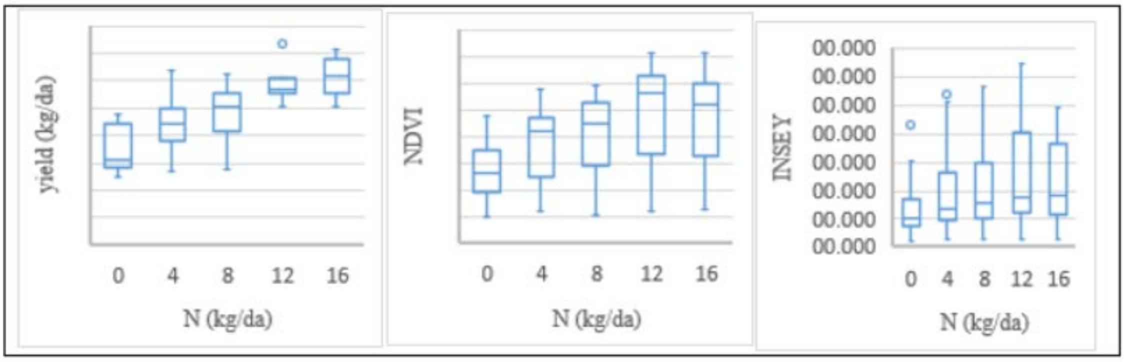


Figure 9. Yield, NDVI, INSEY values at different nitrogen doses.

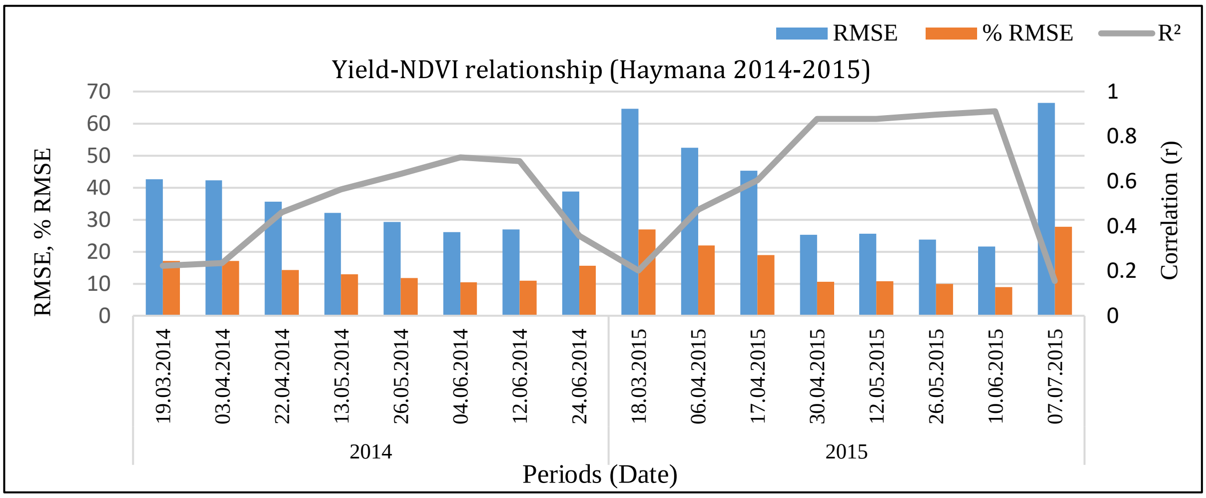


Figure 10. Yield-NDVI relationship (Haymana 2014-2015).

Correlation between grain yield and vegetation index between 2014-2015 indicated an increase from the tillering period (06 April 2015) until the middle of the milking period. However, the highest correlation values were found in the middle of the flowering period (26 May 2015), similar to the 2013-2014 (r = 0.943-0.964). In this case, the band ranges to be taken as a basis for early yield estimation were determined as the region within the red (Red), red edge (Red Edge) and early NIR bands. As a result, spectral indices (NVI, SR-8, SR-11, SR-5) and their regression estimation equations were obtained using these bands in early yield estimation. In the study, regression equations were used to reveal the relationships between actual yields and estimated yields calculated from the indices. In this way, indices and effective band regions that can be used in yield estimation were revealed.

3.5. Yield-NDVI-INSEY relationships according to different phenological periods in wheat

The difference in yield NDVI and INSEY values obtained from the plots in 2014 and 2015 by applying different nitrogen doses are given in the Box-Whisker plot (Figure 9).

The relationship graphs between NDVI measurements two years vegetation period and the calculated INSEY values and yields are shown in Figure 12. It is observed that the relationship between INSEY and yield is higher in 2015 than in 2014. The relationship between INSEY and yield increases during the periods when plant height increased, and soil coverage of the plant increased during the year. This relationship is lowest in March, increases in April and May, and reached its highest level in late May and early June. This relationship decreases towards the end of June when the plant starts to turn yellow. The response of the plant to the applied nitrogen is an important criterion to evaluate the nitrogen requirement of the plant to obtain maximum yield (Fageria and Baligar 2005). The relationship between NDVI and yield is further increased by dividing NDVI by GDD (GDD=[(Tmin+Tmax)/2-4.4 °C]), which is measured from the sowing date throughout development (Lukina et al., 2001). In the relationship between NDVI and yield, the highest yield values were found on 04 June 2014 (r = 0.707, RMSE=26.08, % RMSE=10.51) in 2014 and on 10.06.2015 (r = 0.912, RMSE=21.55, % RMSE=8.99) in 2015 (Figure 10). The correlations between biophysical characteristics (biomass, grain yield) influencing plant growth and various vegetation indices (NDVI, DVI, RVI, MTVI, OSAVI, etc.) derived from spectral reflectance values collected through ground measurements of plants within the 330-1142 nm range were investigated, and regression prediction equations were developed for predicting agronomic characteristics across different phenological development stages. The impact of varying nitrogen fertilizer doses on the spectral reflectance characteristics of wheat during different growth stages was determined, and the optimal spectral band combinations, band intervals, and timing of nitrogen application, which directly influence yield, were determined. Correlation (r) relations between single band reflectance values (at 3 nm wavelength) and biomass (ton/da.) were analyzed, high correlation values were observed between biomass and wavelengths in the band range of 409-549 nm in the visible region (Feekes 4-7) and in the red edge region (700-770 nm), especially in the early period (Feekes 4-7), considering the early, late and the whole development period. In the late period (Feekes 8-10), an increasing correlation was observed in the band range 530-680 nm. in the visible region, a negative decrease in the correlation was observed in the red edge region (Red Edge 700-750 nm), and no significant change in the correlation was observed in the near infrared region (NIR) with a wavelength of 750-1000 nm Considering the whole period (Feekes 4-10), the highest correlation change was observed in the red edge region (Red Edge 700-750 nm). Relationships between agronomic traits and spectral indices were analyzed in 2014-2015 vegetation period. The relationships between the index values calculated according to the period when the spectral readings were taken, and biomass and yield were analyzed. When the Correlation (r) relations between Biomass (ton/da.) and Single band Reflectance values (at 3 nm) of wheat in Haymanada İkizce experimental area according to different development periods in 2014-2015, it was observed that there was an increasing correlation in the visible region in the 530-680 nm band range in the visible region, a negative decrease was observed in the correlation in the red region (Red Edge 700-750 nm), and no significant change was observed in the correlation in the near infrared region (NIR) with a wavelength of 750-1000 nm Considering different phenological periods, the highest biological yield values were found at 12 kg/da nitrogen dose in the late period (10 June 2015). Especially considering the late and the whole development periods, high correlation values were found in the blue band range (400-500 nm) in the visible region and in the green and red bands range (570-680 nm) in the visible region. The highest correlations between biomass (kg/ha) and spectral indices were determined at tillering (06 April 2015) and stalk emergence (12 May 2015), and correlation values ranged between R^2= 0.771-0.735 for the first ten indices. The prominent indices in this period were NDI-2, SR-11, SR-17, SR-9, ZTM, SR-1, SR-16, OVI-4, SR-10 and NDVI-2. These indices were in the 550-900 nm band range, in the green + red + red edge (Red Edge) + NIR range on the electromagnetic spectrum. When the relationships between grain yield-spectral indices for different phenological periods in Haymana 2014-2015 period were examined, the highest correlation values were found in flowering period (26 May 2015), milking period (10 June 2015) and stalk emergence period (12 May 2015), respectively. The prominent indices in these periods are NVI (673-777), SR-8 (550-860), SR-11 (680-900), SR-5 (650-700), SR-17 (560-810), OVI (730-760), SR-2 (550-800), SR-1 (670-801), ZTM (710-750), SR-16

(705-750). Green+Red+Red Edge+Near Infrared (NIR) bands have come to the forefront to be used in yield estimation. These results obtained at Haymana location showed that the spectral readings obtained during the flowering period of winter wheat and the indices and yield estimation equations obtained by using the spectral band combinations related to them can be used for yield estimation in Ankara province conditions.

4. Conclusion

The growth stage of the plant has gained importance for future research. It will be aimed at which nitrogen fertilizer application is necessary for the highest yield at which stage of the plant. Nowadays, many hyperspectral vegetation indices have been developed to determine yield estimate in wheat. However, many of them are still under evaluation and need to be re-tested in different locations according to different growth stages of the plant, and years

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Conflict of interest

The authors declare no conflicts of interest.

Authorship contribution statement

M.A: Investigation, methodology, conceptualization. H.Y: Validation, formal analysis, writing - original draft.

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