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Comparison of Spectral Indices Derived from QUICKBIRD and Ground Based Hyper-Spectral Data for Winter Wheat

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Abstract: Spectral indices, obtained from ground based hyper-spectral instruments such as a spectroradiometer and satellite-based QUICKBIRD images, are a reliable means of collecting field information to determine early conditions of vegetation. Spectral indices can also be used to identify "problem" sites in a field. In this study, we examined the spectral indices, calculated from ground based hyper-spectral data and QUICKBIRD image, capabilities to determine nitrogen response of corn in field conditions. It is also aimed that to determine the spectral relationship between QUICKBIRD satellite imagery and ground based hyper-spectral data at two growth stages. Four common vegetation indices for winter wheat (Triticum aestium cv. Gonen 98) at the booting and harvesting stages with various nitrogen levels were used for comparison. Indices tested were Normalized Difference Vegetation Index Red (NDVIr), Normalized Difference Vegetation Index Green (NDVIg), Simple Ratio Index (SRI) and Soil-Adjusted Vegetation Index (SAVI). The relationships among the indices calculated from ground based hyper-spectral data and QUICKBIRD images were all significant ($P<0.05$) at booting stages. The R^2 between the Hyper-spectral data and QUICKBIRD images for 180 kg nitrogen per ha and 240 kg nitrogen per ha treatments were higher than those of 60 kg nitrogen per ha and 120 kg nitrogen per ha at the booting stage. The predicted R^2 value for SNDVIg was the highest in 120 kg nitrogen per ha treatments (38.3) while the lowest was in 240 kg nitrogen per ha (30.5) at harvesting stage. We concluded that the booting stage had greater potential for collecting ground based hyper-spectral data to calibrate the QUICKBIRD imagery using vegetation indices comparing the harvesting stage.

Key words: Hyper-spectral data · QUICKBIRD · Vegetation index · Winter wheat · Nitrogen

INTRODUCTION

Since the early 1970s, the capability of remote sensing has greatly improved due to advancements in electronics and research that have revealed spectral identifiers for detecting specific crop characteristics [1]. In more developed countries such as the USA, Germany and Canada, relatively expensive equipments such as aerial imagery have been more widely applied for research and commercial operations for detecting specific crop characteristics. Relatively low spatial resolution kept satellite-based remote sensing imagery to a very limited number of applications in precision agriculture which requires detailed information about soil and crop conditions. In fact, a spatial resolution of a few meters is required for most agricultural applications [2, 3].

QUICKBIRD satellite imagery has a 2.4 meter (m) (at nadir) instantaneous field of view (IFOV) for its four channels of multispectral data (blue, green, red, near IR) and 0.61 m IFOV for its one panchromatic channel [4]. Yang *et al.* [3] mentioned that QUICKBIRD has significantly narrowed the gap in spatial resolution between satellite and airborne imagery. In addition to its high spatial resolution, QUICKBIRD has image data with 11-bit radiometric resolution.

Many researchers have used the vegetation indices

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for different purposes [5-12]. Vegetation indices are the basic form of the spectral characteristics of vegetation, which can be calculated from multispectral data using mathematical combinations between bands or selected wavelengths. These vegetation indices are operated by contrasting intense chlorophyll pigment absorptions in the visible region of electromagnetic spectrum against the high reflectivity of plant materials in the near infrared (NIR) region of electromagnetic spectrum. The value of vegetation indices lies in their potential use to estimate vegetation variables such as nitrogen status of leaves and stress levels of vegetation [13] caused by agricultural and environmental conditions.

A number of spectral reflectance indices have been developed to estimate plant features related to the development of the total photosynthetic area of the canopy. The most widely used index is the normalized difference vegetation index (NDVI), which was originally proposed as a means of estimating green biomass [14, 15] chlorophyll content [10, 11] and grain yield [16, 17]. Jordan [18] and Serrano *et al.* [19] have shown that simple ratio Index (SRII) or the ratio vegetation index may provide reliable information for winter wheat yield forecasting under stress conditions [20]. SRII and NDVI had been used as biophysical indicators for crops [11, 14, 16]. Some other indices include Different Vegetation Index (DVI) [12], Soil-Adjusted Vegetation Index (SAVI) [21] and Optimized Soil Adjusted Vegetation Index (OSAVI) [22], which also have been used to determine vegetation variability.

Analytical Spectral Devices (ASD) as a field based remote sensing instrument is useful to collect spectral data from agricultural field for analysis of plant physical and physiological parameters [23]. ASD instruments are ideally suited for rapid in-field analysis of both living plant tissue and dried plant materials for the determination of nitrogen and water stress levels [24]. Reflectance data collected by spectroradiometer is also used to model more complex attributes such as soil nutrient requirements and prediction of crop yield and identification of corn hybrids for biomass.

The objectives of this study were to evaluate the use of hyper-spectral data and QUICKBIRD image individually in determination of nitrogen response of winter wheat and to compare the QUICKBIRD to hyper-spectral data using four common vegetation indices at the different growth stages.

MATERIALS AND METHODS

Study Area and Preparation of Dataset: This study was conducted at the Kaanlar Kumkale farm, which is located inside the Troia National Park, 20 km West of Canakkale Province, Turkey (Figure 1). The geographic coordinates at the centre of the study area were 39° 54'N, 26° 17'E. The study site has been an intensively cropped area. The soil in study area was dark brown fine sandy loam with pH 7.6. For this study, winter wheat was planted in October 10, 2005 and harvested on June 22, 2006. The seeding rate was approximately 500 seeds/m^2.

The field experiment was a randomized block design with three replicates. Different levels of nitrogen (60, 120, 180 and 240 kg ha^{-1}) were individually applied in plots (hereafter referred to as N60, N120, N180, N240). Each plot was 25 m by 33 m in size. The number of pixels for each plot was determined for images as 108 (Figure 1). Nitrogen was applied to the field at two stages. Diammonium phosphate (DAP) as the first part of nitrogen (60 kg Nha^{-1}) was applied in all plots by sowing. The second part of nitrogen was applied at tiller formation stage depending on treatments as follows 0, 60, 120, 180 kg N ha^{-1} with urea. Grain yield was determined by harvesting 1 m^2 area in each plot and then converted to kilogram per hectare.

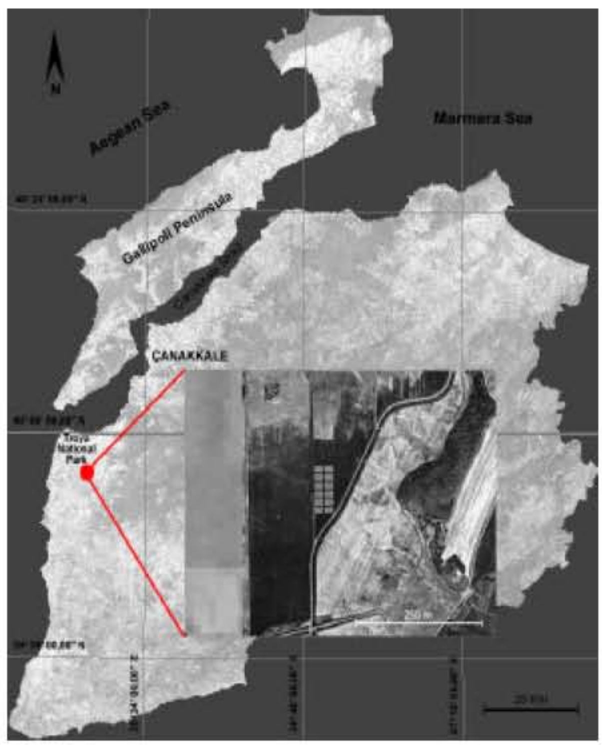

Fig. 1: Plot design of the study site

Table 1: Indices used for comparison of QUICKBIRD image and ASD HH spectroradiometer data

Indexes	Formula	Reference
NDVIr	$NDVIr = \frac{(NIR - Red)}{(Nir + Red)}$	Rouse, 1973
NDVIg	$NDVIg = \frac{(NIR - Green)}{(Nir + Green)}$	Gitelson *et al.*, 1996
SRII	$SRI = \frac{NIR}{Red}$	Jordan, 1969
SAVI	$SAVI = \frac{(NIR - Red)}{(NIR + Red + 0.5)} * 1.5$	Huete, 1988

Spectral Data and Analysis: QUICKBIRD images taken on April 17, 2006 and on June 18, 2006 were used in this study. Each image covered an area 8 km by 8 km square (64 km^2). QUICKBIRD imagery has an 11-bit radiometric resolution in four spectral bands: blue (450-520 nm), green (520-600 nm), red (630-690 nm) and NIR (760-900 nm) and 1 panchromatic band. The resolution of the multispectral band image was 2.4 m (off-nadir). Prior to delivery, the imagery was radiometrically and geometrically corrected using World Geodetic Survey 1984 (WGS84) datum and the Universal Transverse Mercator (UTM) coordinate system. To improve the positional accuracy, the pre-rectified images were further rectified based on a set of ground control points collected from the study area sub meter accuracy global positioning system (GPS). After plot areas were masked out from images, Normalized Difference Vegetation Index Red (NDVIr) [15], Normalized Difference Vegetation Index Green (NDVIg) [25, 26], Simple Ratio Index (SRI) [18], Soil-Adjusted Vegetation Index (SAVI) [21] were calculated at booting and harvesting stages (Table 1). All procedures for image rectification and image processing were performed using Leica ERDAS Imagine image processing software.

Canopy reflectance was measured with a narrow-bandwidth visible-near-infrared Portable Field Spec Handheld Spectroradiometer (Analytical Spectral Devices, Inc.) (ASD HH) fitted with 10° field of view optic. The diameter of measured surface area was 9 cm. The ASD HH instrument detects 512 continuous bands with a 1.5 nm sampling interval sensitive in the 325 to 1075 nm portion of the spectrum. The spectral IFOV of the ASD HH spectroradiometer is 3.5 nm for the region 325-1075 nm [23].

An ASD HH reflectance measurement was carried out and later on coordinates of this location were marked on index images. The reflectance spectrum was calculated in real time as the ratio between the reflected and the incident spectra on canopy, where the incident spectrum was periodically obtained from the light reflected by a barium sulphate standard panel before and immediately after each measurement (Spectralon Labshere, North Sutton, NH) [24]. All corresponding measurements for winter wheat were carried out on the same day and under sunny conditions between 12:00 and 14:00 local time. Each scan was saved on a portable computer on the field and transferred to laboratory computer for further analysis. The ASD HH spectroradiometer was placed above each plant canopy at 50 cm. Five spectral reflectance measurements were taken for each plot, each being the average of ten scans.

A total of 600 (5 measurements x 10 scans each x 12 plots) reflectance values were used to determine 60 points (5 measurements x 12 plots) at which NDVIr, NDVIg, SRI and SAVI indices were calculated. Mean separation for grain yield was carried out using LSD test at 0.05 significance. Indices were compared using regression analysis to determine the relationship between space origin indices and field based indices.

RESULTS

Color infrared composites of the QUICKBIRD images for two different growth stages: booting and harvesting (April 17, 2006 and June 18, 2006, respectively) (Figure 2). Healthy plants showed a magenta color while stressed plants and areas with large soil exposure were blue. The booting stage image clearly reveals differences between plant growth patterns generated by the different nitrogen treatments, which was better than the harvest stage image. After visual inspection, the harvesting stage image did not show a noticeable reflection among the nitrogen treatments (Figure 2). It is important to mention that, at the harvesting stage, the magenta tone on the image was because of weeds at the side of the drainage channel shown (Figure 2). As a consequence, all measurements were taken in the blue area.

The relationships between index values calculated from Hyper-spectral measurements were referred as ASDNDVIr, ASDNDVIg, ASDSRI and ASDSAVI and satellite based index values were referred as SNDVIr, SNDVIg, SSRII and SSAVI. Satellite predicted indices were calculated using linear regression models for each of the stages to show relative means of the relationship between the field based index values and space based index values.

At the booting stage, QUICKBIRD based indices detected significant differences ($P<0.05$) between nitrogen levels (Table 2). All vegetation indices calculated from

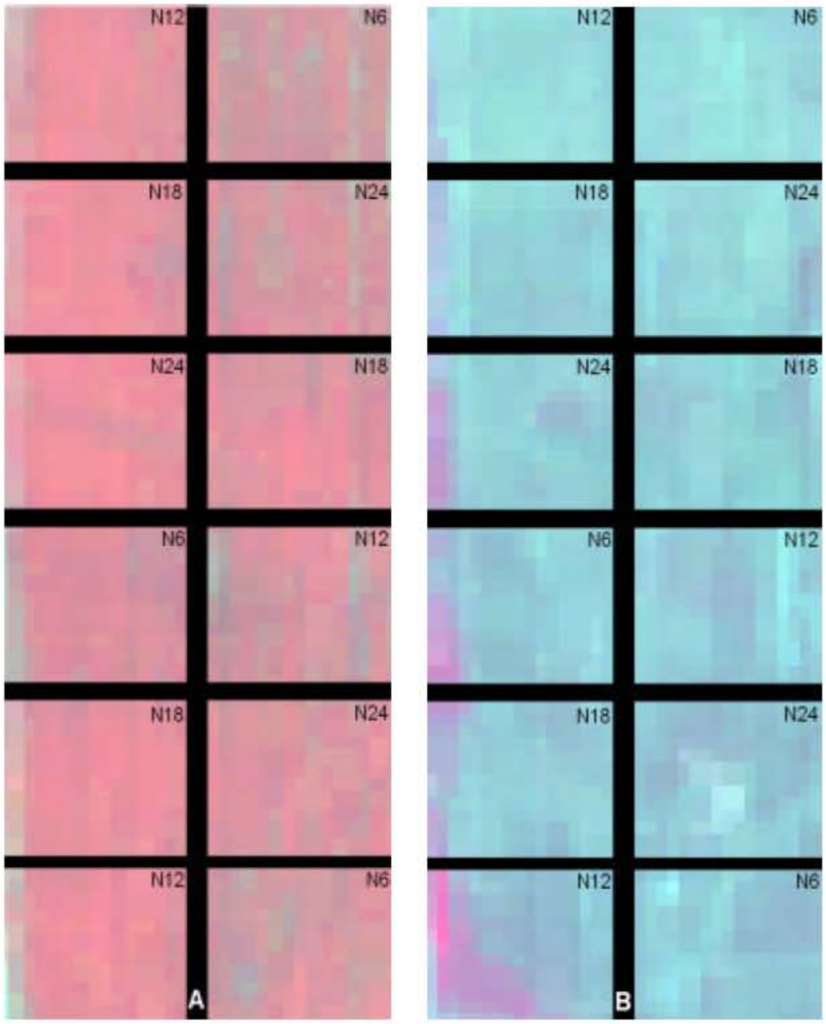

Fig. 2: Satellite images (RGB 432): A) April 17 2006, booting stage. B) June 18 2006 harvesting stage

QUICKBIRD at this growth stage increased with increasing the nitrogen levels. In general, there was a similar pattern for all indices obtained from different nitrogen treatments (Table 2). In addition, a significant difference was found between the N60 and N120 treatments which were also booth significantly different from N180 and N240.

Hyper-spectral based indices values showed that there were significant differences between the nitrogen levels at the booting stage as in QUICKBIRD based indices (Table 2). Similarly, increases in nitrogen levels resulted in increases in vegetation indices values. Unlike to QUICKBIRD based indices, there was not a distinct pattern among hyper-spectral based vegetation indices. Moreover, ASDSRI and ASDSAVI able to detect the differences between all nitrogen levels more sensitively compare to ASDNDVIr and ASDNDVIg.

At the harvesting stage, QUICKBIRD based vegetation indices increased with increasing nitrogen levels as in the booting stage. However, these significant differences between nitrogen levels for vegetation indices varied less than those at booting stage. For all indices, N60 was significantly different and lower than the rest of the nitrogen treatments.

When hyper-spectral data is considered, all vegetation indices significantly varied depending on nitrogen levels. At the harvest stage, nitrogen treatment effect on hyper-spectral based vegetation indices was similar to booting stage. However, patterns of ASDNDVIr and ASDNDVIg were different from the pattern of ASDSRI and ASDSAVI. In vegetation indices ASDSRI and ASDSAVI, the values for each nitrogen treatments significantly differed from each other. In other words, the differences between all nitrogen levels were significant.

Tble 2: Mean values of the different indices for ASD hand held spectroradiometer and QUICKBIRD image

Booting Stage								
N	SNDVIr	SNDVIg	SSRI	SSAVI	ASDNDVIr	ASDNDVIg	ASDSRI	ASDSAVI
60	0.742±0.010a	0.542±0.017a	6.803±0.455a	1.394±0.029a	0.816±0.047a	0.753±0.055a	10.564±2.784a	1.134±0.059a
120	0.780±0.011b	0.590±0.015b	8.117±0.419b	1.463±0.019b	0.853±0.053b	0.770±0.052a	14.408±5.151b	1.171±0.075b
180	0.791±0.004c	0.604±0.009c	8.586±0.202c	1.484±0.008c	0.929±0.007c	0.848±0.018b	27.542±3.000c	1.217±0.075c
240	0.792±0.004c	0.609±0.008c	8.652±0.195c	1.487±0.008c	0.943±0.008c	0.897±0.284c	35.360±6.450d	1.316±0.021d
LSD	0.0049	0.0590	0.1480	0.0922	0.202	0.0205	0.2160	0.0334
Harvesting Stage								
N	SNDVIr	SNDVIg	SSRI	SSAVI	ASDNDVIr	ASDNDVIg	ASDSRI	ASDSAVI
60	0.297±0.042a	0.539±0.077a	1.858±0.167a	0.295±0.039a	0.188±0.005a	0.107±0.005a	1.464±0.018a	0.475±0.015a
120	0.365±0.024b	0.585±0.050b	2.136±0.111b	0.341±0.038b	0.208±0.014b	0.112±0.010b	1.547±0.046b	0.526±0.036b
180	0.364±0.049b	0.570±0.072b	2.164±0.249b	0.353±0.042b	0.222±0.020b	0.116±0.013b	1.575±0.070c	0.562±0.051c
240	0.369±0.023b	0.581±0.060b	2.175±0.127b	0.367±0.022b	0.239±0.019b	0.119±0.011b	1.579±0.066c	0.564±0.049c
LSD	0.0186	0.0317	0.0840	0.0226	0.011	0.0068	0.0306	0.0223

n= 2020

SNDVIr= Satellite Derived Normalized Difference Vegetation Index red and NIR bands

SNDVIg= Satellite Derived Normalized Difference Vegetation Index green and NIR bands

SSRII = Satellite Derived Simple Ratio index red and NIR

SSAVI = Satellite Derived Soil Adjusted Vegetation index red and NIR bands

ASDNDVIr= ASD HH Derived Normalized Difference Vegetation Index red and NIR broad bands

ASDNDVIg= ASD HH Derived Normalized Difference Vegetation Index green and NIR broad bands

ASDSRI = ASD HH Derived Simple Ratio index red and NIR broad bands

ASDSAVI = ASD HH Derived Soil Adjusted Vegetation index red and NIR broad band

Table 3: Regression results for relating grain yield to the best predicted Satellite (QUICKBIRD) based indices and ASD HH spectroradiometer based indices for booting stage

	Predicted Equation	R-Sq %
N60		
SNDVIr	0.545 + 0.242 ASDNDVIr	54.1
SNDVIg	0.393 + 0.199 ASDNDVIg	40.7
SSRII	5.64 + 0.110 ASDSRI	45.5
SSAVI	1.02 + 0.334 ASDSAVI	45.1
N120		
SNDVIr	0.656 + 0.146 ASDNDVIr	55.0
SNDVIg	0.429 + 0.209 ASDNDVIg	50.8
SSRII	7.24 + 0.0611 ASDSRI	56.3
SSAVI	1.28 + 0.160 ASDSAVI	38.1
N180		
SNDVIr	0.389 + 0.433 ASDNDVIr	59.1
SNDVIg	0.237 + 0.432 ASDNDVI	67.5
SSRII	7.12 + 0.0534 ASDSRI	62.4
SSAVI	1.39 + 0.0763 ASDSAVI	48.7
N240		
SNDVIr	0.412 + 0.404 ASDNDVIr	64.4
SNDVIg	0.395 + 0.238 ASDNDVIg	59.8
SSRII	7.86 + 0.0224 ASDSRI	54.6
SSAVI	ASDSAVI = - 1.54 + 1.92 SSAVI	50.3

Table 4: Grain yield production for different N treatments

N kg da^{-1}	Grain Yield(kg ha^{-1})
240	4430a
180	4390a
120	4040b
60	3920c
$LSD_{0.05}$=60.78	

Regression analyses were carried out in order to evaluate the relationships between hyper-spectral data with QUICKBIRD images. In Table 3, overall, R^2 values of all predicted satellite indices for N180 and N240 were higher than those of N60 and N120 at the booting stage. When R^2 is considered individually, predicted SNDVIr values increased with increasing nitrogen treatments. The highest R^2 for predicted SNDVIr was calculated for N240 with 64.4 whereas the lowest was for N60 treatment at the booting stage (54.1). The predicted R^2 value for SNDVIg was the highest in N180 treatments (67.5) while the lowest was in N60 (40.7). The lowest R^2 predicted satellite indices among all nitrogen treatments (N60, N120, N180 and N240) were calculated for SSAVI (45.1, 38.1, 48.7 and 50.3 respectively) compared to SNDVIr, SNDVIg and SSRI (Table 3).

The R^2 of the predicted satellite indices at harvesting stage did not show any distinct pattern in terms of different nitrogen applications (Table 4). The highest R^2 for predicted SNDVIr was calculated for N120 with 47.9 whereas the lowest was for N240 treatment at harvesting stage (40.0). The predicted R^2 value for SNDVIg was the highest in N120 treatments (38.3) while the lowest was in N240 (30.5). The predicted R^2 value for SSRI was the highest in N120 treatments (50.2) while the lowest was in N240 (37.0). The predicted R^2 value for SSAVI was the highest in N240 treatments (46.9) while the lowest was in N120 (25.0) (Table 4).

DISCUSSION

Satellite imagery was able to monitor plant growth variability and grain yield [3]. In this study, QUICKBIRD images were also able to determine the plant variability at the booting stage of winter wheat, but not at the harvesting stage. At booting stage, all vegetation indices' values generated from both QUICKBIRD and ground based hyper-spectral data were higher than those at harvesting stage. Since high values of NDVIr, NDVIg, SRI and SAVI indicated the healthy crop, the best time for QUICKBIRD image acquired time for winter wheat is the booting stage. This could be attributed to the higher reflectance values for NIR bands recorded from the plants grown at higher nitrogen concentrations, which increase the chlorophyll content in plant parts. Increasing the chlorophyll content on plant leaves resulted in high reflectance values at the booting stages. At the harvesting stage, the lower chlorophyll content, as well as the soil effect, caused a high reflection in the visible region of the spectrum and lower reflectance at NIR region.

The relationship between hyper-spectral based and QUICKBIRD based vegetation indices was observed from NDVIr index for N60 (54.1) whereas lowest relationship was obtained from NDVIg (40.7) at booting stages. The high relationships for NDVIr, NDVIg, SRI were obtained from N240 (64.4), N180 (67.5), N180 (62.4) respectively. This showed that the high nitrogen treatments (N240 and N180) provide higher relationship with QUICKBIRD based indices. This indicated that hyper-spectral data collected from field by spectro-radiometer seems to have potential for calibration of the QUICKBIRD imagery using vegetation indices at booting stage with no nitrogen stress. Unlikely the booting stage, there was no significant pattern at the harvesting stage. The lowest NDVIr and NDVIg values were observed from N240 (40.0) and N240 (30.5) respectively at the harvesting stage. The highest relationship for SRI was also obtained from N120 (50.2). Calibrating the high resolution image such as QUICKBIRD using hyper-spectral data obtained from field is possible. However this progress should not be done at the harvesting stage. Collecting the field data by spectro-radiometer is a relatively easy method, but limited the size of the study area. In order to solve this problem, high resolution satellite imagery is needed for large areas.

In addition, there were significant differences among nitrogen treatments in terms of grain yield per ha (Table 5). Similar to the pattern of predicted R2 values of indices, the highest grain yield was obtained from N240 treatments followed by N180, N120, and N60 in booting stage. Higher NDVIg value compared with NDVIr values could be attributed to the fact that NDVIg value tends to determine chlorophyll in yellow to dark green vegetation.

Table 5: Regression results for relating grain yield to the best predicted QUICKBIRD based indices with ASD HH spectroradiometer based indices for harvesting stage

	Predicted Equation	R-Sq %
N60		
SNDVIr	- 0.610 + 4.82 ASDNDVIr	45.4
SNDVIg	- 0.315 + 7.95 ASDNDVIg	34.5
SSRII	- 7.38 + 6.31 ASDSRI	46.6
SSAVI	- 0.431 + 1.53 ASDSAVI	33.9
N120		
SNDVIr	0.0948 + 1.18 ASDNDVI	47.9
SNDVIg	0.284 + 2.91 ASDNDVIg	38.3
SSRII	- 0.553 + 1.69 ASDSRI	50.2
SSAVI	0 0.061 + 0.532 ASDSAVI	25
N180		
SNDVIr	- 0.003 + 1.65 ASDNDVIr	47.3
SNDVIg	0.194 + 3.22 ASDNDVIg	33.5
SSRII	- 1.61 + 2.40 ASDSRI	46.0
SSAVI	0.083 + 0.481 ASDSAVI	35.1
N240		
SNDVIr	0.182 + 0.780 ASDNDVIr	40.0
SNDVIg	0.206 + 2.97 ASDNDVIg	30.5
SSRII	0.274 + 1.16 ASDSRI	37.0
SSAVI	0.175 + 0.318 ASDSAVI	46.9

Since spectroradiometer data collection requires several trips to field, QUICKBIRD could help to determine nitrogen effect on winter wheat using indices such as NDVIr and NDVIg and SSRI thus reducing the need for field work. However, for precision agriculture purposes, we assumed that to determine the early stage of wheat more precisely, the spatial resolution of the satellite imagery could be better than 2.4 m resolution. Because of this, nitrogen deficiency and other type of problem in small areas can not be detected with a 2.4m resolution. Therefore, QUICKBIRD is not appropriate to most cases in Turkey. However there are new technologies being developed such as unmanned aircraft that can rectify this situation. Digital color infrared images obtained by aircraft have been used in agriculture fields to determine drought problematic area, nitrogen deficiency, mapping of potential crop yield and geo-positioned agricultural applications such as fertilizers, pestices and herbicides.

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