Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi 25 (1):57-64, 2020
(*Mustafa Kemal University Journal of Agricultural Sciences* 25 (1):57-64, 2020)
e-ISSN: 2667-7733
http://dergipark.org.tr/mkutbd

ARAŞTIRMA MAKALESİ RESEARCH ARTICLE

Comparing a chromameter and a hand held NDVI meter to predict nitrogen and water content of turfgrass

Çim bitkisinin azot ve su içeriği tahmini için Renk ölçer ve NDVI ölçerin karşılaştırılması

Muharrem KESKİN[1], Çağatay ÇAM[1], Yunus Emre ŞEKERLİ[1]
[1]*Hatay Mustafa Kemal University, Faculty of Agriculture, Department of Biosystems Engineering, Antakya-Hatay, Turkey.*

MAKALE BİLGİSİ / ARTICLE INFO

***Makale tarihçesi / Article history*:**
DOI: 10.37908/mkutbd.646974
Geliş tarihi /Received:14.11.2019
Kabul tarihi/Accepted:16.12.2019

***Keywords*:**
Turfgrass, proximal sensing, nitrogen content, water content, NDVI meter, chromameter.

Corresponding author: Muharrem KESKİN
: mkeskinhatay@gmail.com

Ö Z E T / A B S T R A C T

Aims: Nitrogen content (NC) and water content (WC) of turfgrass is traditionally determined by laboratory analysis which is time-consuming, tiresome, laborious and costly. The aim of this study was to examine the suitability of two hand held optical instruments (GreenSeeker NDVI meter and chromameter) to evaluate NC and WC of turfgrass.
Methods and Results: Six turfgrass plots of 1 m x 1 m with a mixture of five different species were used and variable rate nitrogen fertilizer (N_0: 0 g N m^{-2}, N_1: 2.5 g N m^{-2}, N_2: 5 g N m^{-2}) was applied. NDVI measurements were taken at around noon with a GreenSeeker NDVI instrument from the plots. After mowing, the color values of the clippings were measured using a hand-held chromameter. The data were analyzed using correlation and partial least square regression (PLSR). A high correlation was found between leaf NC, WC, NDVI and color values. The leaf NC (%) can be estimated from the NDVI (R^2val=0.73, SEP=0.19%) and color values (L*a*b*C*h°) (R^2val=0.76; SEP=0.18%). Also, it was found that the WC (%) can be predicted from the NDVI (R^2val=0.40, SEP=5.07%) and color values (L*C*h°) (R^2val=0.69; SEP=3.67%) with slightly lower accuracy.
Conclusions: Turfgrass leaf NC can be estimated with either an NDVI instrument (R^2=0.73, SEP=0.19%) or a chromameter (R^2=0.76, 0.18%) with reasonable accuracy in a more objective and economical way.
Significance and Impact of the Study: Considering the reduction in time and cost required in the NC and WC analysis, we think that results of this study may be useful for turf field managers. Also, nitrogen determination with sensors will be a more eco-friendly way if used by managers.

Atıf / Citation: Keskin M, Çam Ç, Şekerli YE (2020) Comparing a chromameter and a hand held NDVI meter to predict nitrogen and water content of turfgrass. *MKU. Tar. Bil. Derg.* 25(1) : 57-64. DOI: 10.37908/mkutbd.646974

INTRODUCTION

Turfgrass is mainly utilized in tourism areas, urban green areas, and sports fields including football fields, soccer fields, golf courses, etc. Fertilization is an important cultural practice in turfgrass maintenance. Nitrogen (N) is the most important mineral nutrient in turfgrass fertilization. If the chemical fertilizers and pesticides are not applied at right time and right amount in accordance with the needs of the plants, various problems may occur. The fertilizer requirement is ideally determined by soil or plant tissue chemical analysis in a laboratory. However, this method is time-consuming, labor-intensive, costly and tedious (Rodriguez and Miller, 2000; Keskin et al., 2004; Keskin et al., 2013). Also the chemicals used in the analyses pose a health risk for the lab technicians. Hence, fertilizer application in turfgrass is usually carried out based on the visual evaluation or a timetable depending on the qualification and experience of the field manager without chemical analysis (Keskin et al., 2004; Keskin et al., 2008). In this case, the amount of fertilizer applied may be more or less than the required amount. Application of fertilizers in lower rates may cause poor quality turfgrass while excessive amounts increase the costs and decrease the profitability of turfgrass facilities (Hocaoglu, 2010). In recent years, due to the intensive application of chemical fertilizers, pollution of surface and groundwater resources has become an important problem (Keskin et al., 2004; Keskin et al., 2013). In addition, fertilizer leaching (especially N and P) contributes to degradations in water quality (objectionable taste and odor in drinking water, fish kills, or acute toxicity or poisoning) through algal bloom growth due to nutrient enrichment (CAST, 2019). For instance, when the nitrate content in drinking water is high, human health can be negatively affected. In the US and Turkey, maximum nitrate content limit in drinking water is 10 ppm and 50 ppm, respectively (EPA, 2012; Turkish Official Gazette, 2004). Thus, there is a need for less labor-intensive, low-cost and practical methods to determine the leaf mineral nutrient content and fertilizer requirement of turfgrass (Rodriguez and Miller, 2000; Keskin et al., 2004; Keskin et al., 2018).

There are some practical optical measurement systems developed by commercial firms used in scientific studies including chlorophyll meter, spectroradiometer, spectrophotometer, digital camera, chromameter, fluorescence meter, NIR spectroscopy, etc. These systems have been used to determine plant nitrogen requirement in various plants (Rodriguez and Miller, 2000; Keskin et al., 2004; Keskin et al., 2018).

As a result of literature review, it was observed that optical based sensors are mostly used for field crops to provide sufficient nitrogen fertilizer especially in variable rate applications (VRA) as a part of Precision Agriculture Technologies. There has been a limited number of research on the use of practical optical systems in turfgrass management. Therefore, the aim of this study was to evaluate and compare the performance of two different optical measurement systems (NDVI meter and Chromameter) to determine the nitrogen and water content of turfgrass. If the nitrogen concentration can be determined by these devices, there will be no need for chemical analyzes which require high amount of labor, time and cost and also turfgrass nutrient amounts in the plants can be easily and quickly monitored by managers to decide proper fertilizing rate and time.

MATERIALS and METHODS

Experimental field

The results of the analysis of the soil samples taken from the test field are given in Table 1. The results of the analysis were compared with the literature in terms of soil conditions required for turfgrass management.

Table 1. Some soil properties of experimental field

Properties	*Value*	*Comment*
Texture	-	Loam
pH	8.02	Alkaline[1]
EC	136.3 µS/cm	Suitable[1]
Lime	1.57%	Low[2]
OM	0.94%	Low[2]
P	0.09 ppm	Very Low[3]
K	78.67 ppm	Low[4]

EC: Electrical Conductivity, OM: Organic matter
[1]Richards (1954), [2]Kacar (1994), [3]Olsen et al. (1954), [4]Knudsen et al. (1982)

Turfgrass plots

Field experiment was carried out on the test field of Biosystems Engineering Department located on the Tayfur Sokmen Campus of Hatay Mustafa Kemal University (Latitude: 36.32616°N; Longitude: 36.19477°E; Elevation: 115 m) during spring season of 2018. Six field plots each measuring 1.0 by 1.0 m were arranged in a randomized complete block design. The type of turfgrass used on the plots was a mixture of five different species (*Lolium perenne* L. 20%, *Poa pratensis* L. 10%, *Festuca arundinacea* Schreb. 20%, *Festuca rubra* subps. *rubra* 20%, *Cynodon dactylon* L. 30%) usually used on sport fields and recreation areas (DLF Seeds and Sciences, Roskilde, Denmark). Nitrogen fertilizer was applied in the form of urea ($CO(NH_2)_2$) at three monthly rates (N_0: 0 g N m^{-2}, N_1: 2.5 g N m^{-2}, N_2: 5 g N m^{-2}).

Optical sensing systems

a) GreenSeeker Hand-held NDVI meter: It is a commercial active sensing system. The sensor emits red and near infrared (NIR) radiation from the LED sources to the target and acquires reflected radiation. The system calculates and displays Normalized Difference Vegetation Index (NDVI) from the reflectance data. The NDVI value is displayed on the screen after holding the sensor above the plant and pulling the trigger. NDVI ranges from 0.00 to 0.99 for plants where higher values (such as 0.70-0.90) indicate that the plant is healthy and lower values specify that the plant is unhealthy (stressed). Some basic features of this device are summarized in Table 2. The system calculates the NDVI value based on the following equation:

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}} \qquad \text{Eq. (1)}$$

where;
NDVI = Normalized Difference Vegetation Index
R_{NIR} = Reflectance in near infrared band (780 nm)
R_{Red} = Reflectance in red band (660 nm)

Table 2. Some technical features of the two optical devices used in the study

Properties	*NDVI meter*	*Chromameter*
Make and Model	Trimble GreenSeeker Hand-held	Minolta CR-400 Hand-held
Operation principle	Active sensor	Active sensor
Optical radiation source	LED	Xenon lamp
EM bands	Red, NIR	Red, blue, green
Measured value	Reflectance (open area)	Reflectance (closed area)
Calculated parameter	NDVI	L*a*b*, L*C*h°
Operation distance	60-120 cm	Sample surface
Reflectance measurement area	25-50 cm	8 mm / 11 mm

b) Hand-held Chromameter: Chromameters (colorimeter) are the electro-optic devices used in the measurement of numerical color values of objects. Besides the agriculture and food industry, chromameters are widely used in many different areas including health, materials, textile, plastic, dye, pharmacy, cosmetics, etc. (Keskin et al., 2017). It is a three-filter (tristimulus) active system that evaluate three color values (red, green, and blue) by measuring reflected light from sample surface after sending light from its own radiation source (Konica Minolta, 2007). In the present study, the color values of the turfgrass clipping samples were determined with a Minolta CR 400 color measurement system. Some basic features of the device are summarized in Table 2.

NDVI and color data

The NDVI measurement was performed at around noon time with the hand-held GreenSeeker NDVI meter just before mowing (Figure 1). NDVI was measured five times from each trial plot and the average was calculated. In order to ensure that the device is in the same position in each measurement, a wooden frame is used to keep the device in the same vertical distance and angle (Figure 1).

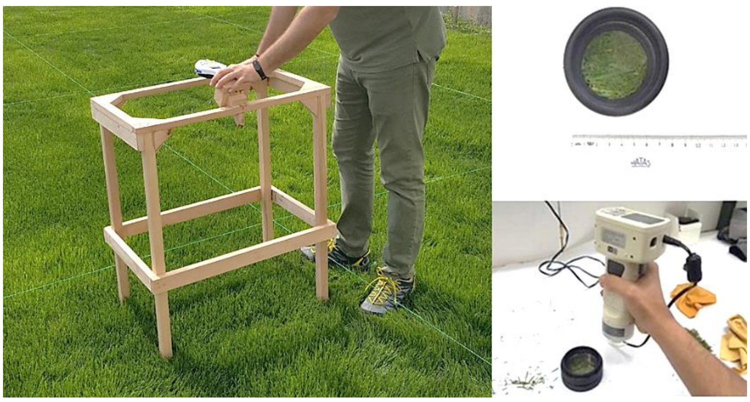

Figure 1. Obtaining NDVI data using an NDVI meter in the field (left) and color data with a chromameter in the laboratory (right)

After the NDVI readings, turfgrass clippings were collected using an electric lawn mower (Bosch ARM32) to a height of 4 cm. A total of thirty samples (6x5=30) were collected from six trial plots in five different occasions with about ten days interval. Clipping samples were stored in plastic bags and transferred to the

Precision Agriculture Technology laboratory immediately in cold chain against chemical and physical changes. The color of turfgrass clippings was evaluated by a chromameter (Figure 1) after it was set to CIE Standard Illuminant C system using L*a*b* and L*C*h° color parameters (Keskin et al., 2017). For each sample, a total of 3 measurements were obtained and the mean value was calculated.

Leaf nitrogen content (NC) and water content (WC) analysis

40 g of clipping samples was weighed with a digital scale with a precision of 0.01 g and then rinsed with distilled water to remove dust and soil particles and put on coarse filter paper to drain excessive water. The samples were dried at 55°C for 72 hours and ground with a hand-mill before chemical analysis (ASABE, 2012). Plant NC was determined according to Macro Kjeldahl method (Kacar and Inal, 2010).

For the analysis of leaf WC, 30 g of turfgrass clipping sample was weighed. The samples were dried in the oven at 103°C for 24 hours to determine dry mass (ASABE, 2012). Leaf WC was calculated by the following equation:

$$WC = \frac{(M_w - M_d)}{M_w} * 100 \qquad \text{Eq. (2)}$$

where;
WC = Leaf water content wet-based (WC) (%)
M_w = Mass of fresh (wet) leaf sample (g)
M_d = Mass of dry leaf sample (g)

Data analysis

Correlation analysis among NDVI, color parameters (L*a*b*, L*C*h°), leaf NC and WC was performed in MS Excel program. In order to develop leaf NC and WC prediction models, Partial Least Square Regression (PLSR) method was used in UnScrambler software. Full Cross Validation method was used for model validation. In the analysis, outlier(s) was determined and removed from the model. Prediction error was determined by RMSEP (Root Mean Square Error of Prediction) value calculated by the following equation (Esbensen, 2009):

$$RMSEP = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \qquad \text{Eq. (3)}$$

where;
RMSEP = Root Mean Square Error of Prediction
y_i = Measured (reference) value,
$\hat{y}_i$ = Predicted value,
n = Number of data.

RESULTS and DISCUSSION

Results of correlation analysis

Turfgrass leaf WC varied between 48.2% and 71.3%, which is close to the values previously reported in different plants (about 71-85% in peanut, 44-67% in cotton, 58-66% in strawberry) (Keskin et al., 2013; Keskin et al., 2016; Keskin et al., 2018). It was also observed that the NC was between 1.4% and 2.6% and NDVI ranged from 0.69 to 0.85. The correlation values among leaf NC, leaf WC, NDVI, and color values are given in Table 3.

Table 3. Correlation coefficients between NC, WC and color values of turfgrass clippings

	WC (%)	NC (%)	L*	a*	b*	C*	h°	NDVI
WC (%)	1.00	•	•	•	•	•	•	•
NC (%)	0.70	1.00	•	•	•	•	•	•
L*	-0.75	-0.85	1.00	•	•	•	•	•
a*	-0.28	0.07	-0.17	1.00	•	•	•	•
b*	-0.43	-0.70	0.71	-0.47	1.00	•	•	•
C*	-0.27	-0.60	0.64	-0.69	0.96	1.00	•	•
h°	0.70	0.60	-0.50	-0.56	-0.47	-0.22	1.00	•
NDVI	0.66	0.86	-0.86	0.16	-0.82	-0.73	0.62	1.00

A high and positive correlation was found between the NC and WC (r=0.70) meaning that the samples with high WC had also high NC (Figure 2). Also a high positive correlation was found between NC and NDVI (r=0.86) leading to a result that turfgrass leaf samples with high NC also has high NDVI value. There was also a moderate positive correlation (r=0.66) between WC and NDVI. This shows that the NDVI value of the turfgrass leaf samples with high WC was also high. On the other hand, high and negative correlation (r= -0.85) was found between the NC and the color brightness value (L*). This result means that light green colored turfgrass leaf samples (with high L* value) had lower NC. Among the color parameters, L* value had the highest correlation with both NC (r=-0.85) and WC (r=-0.75). Also, L* value was the color parameter that showed the highest correlation (r= -0.86) with NDVI among all color parameters (L*, a*, b*, C*, h°) (Table 3). The relationships between leaf NC vs. NDVI and NC vs. L* are given in Figure 2a and Figure 2b, respectively.

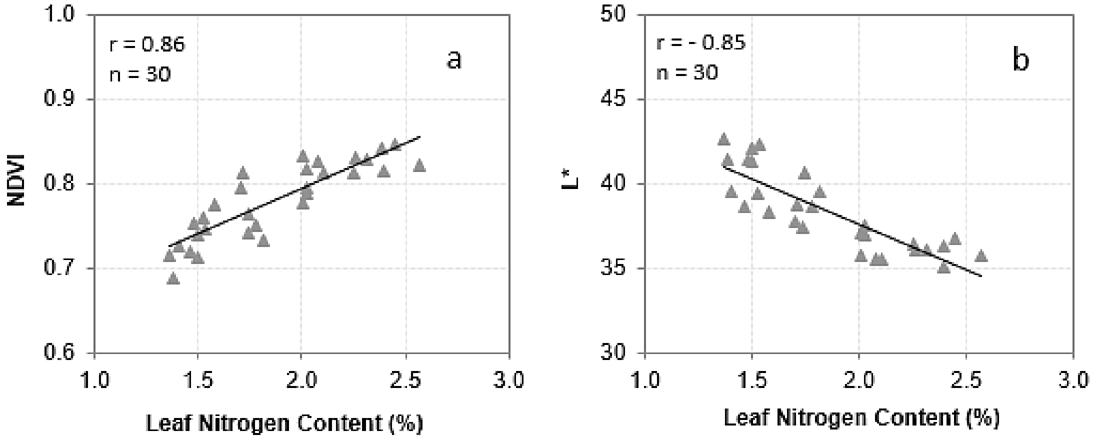

Figure 2. Relationship between leaf nitrogen content and NDVI (a) and L* (b) values

Results of regression analysis

In the study, regression analysis to predict NC of turfgrass samples was carried out and the results are given in Table 4. The best results (lowest SEP and highest R^2 value) were obtained with the model where all color parameters (L*a*b*C*h°) were used together (R^2val=0.76; SEP=0.18 %). Also, the models with L*C*h° and NDVI values gave slightly lower prediction success (Table 4).

Table 4. Regression (PLSR) analysis results for prediction of leaf nitrogen content

Parameter	SEP (%)	SEC (%)	R^2val	R^2cal	N	Nout
NDVI	0.19	0.18	0.73	0.75	30	0
L*	0.20	0.19	0.71	0.72	30	0
a*	0.38	0.36	-0.05	0.06	30	0
b*	0.25	0.23	0.58	0.61	30	1
C*	0.30	0.28	0.40	0.43	30	1
h°	0.31	0.29	0.33	0.35	30	0
L*a*b*	0.20	0.18	0.72	0.74	30	0
L*C*h°	0.18	0.17	0.75	0.77	30	0
L*a*b*C*h°	0.18	0.17	0.76	0.77	30	0

The results of the regression analysis to determine the WC in the turfgrass samples are given in Table 5. The best results for predicting leaf WC were obtained with the model where L*C*h° values were used together (R^2val=0.69; SEP=3.67 %). Lower prediction performance was obtained with L*a*b*C*h° and NDVI values.

Table 5. Regression (PLSR) analysis results for prediction of leaf water content

Parameter	SEP (%)	SEC (%)	R^2val	R^2cal	N	Nout
NDVI	5.07	4.76	0.40	0.44	30	0
L*	4.42	4.16	0.54	0.57	30	0
a*	6.58	6.07	-0.01	0.08	30	0
b*	5.16	4.84	0.41	0.44	30	2
C*	6.04	5.71	0.19	0.22	30	2
h°	4.00	3.77	0.64	0.66	30	3
L*a*b*	4.17	3.89	0.62	0.64	30	2
L*C*h°	3.67	3.40	0.69	0.72	30	1
L*a*b*C*h°	3.73	3.45	0.68	0.71	30	1

According to the results of the modeling analysis, it was determined that the leaf NC could be determined by both hand-held GreenSeeker (NDVI) device (R^2val=0.73; SEP=0.19 %) and hand-held chromameter (L*a*b*C*h°) (R^2val=0.76; SEP=0.18 %) with very similar accuracy. However, the chromameter gave better results than the GreenSeeker (NDVI) device for the prediction of the WC. The developed prediction models are given in Table 6.

Table 6. Developed models for predicting leaf nitrogen and water content

Property	*Optical System*	*Prediction Model*
Nitrogen Content (NC)	GreenSeeker	NC(%)= 6.945 x NDVI - 3.544
	Chromameter	NC(%)= 0.191 - 0.105 x L* - 0.035 x C* + 0.053 x h°
	Chromameter	NC(%)= 0.948 - 0.096 x L* + 0.002 x a* - 0.035 x b* - 0.032 x C* + 0.048 x h°
Water Content (WC)	Chromameter	WC(%)= 3.694 - 1.566 x L* - 0.166 x a* - 0.396 x b* - 0.259 x C* + 1.039 x h°
	Chromameter	WC(%)= -5.783 - 1.684 x L* - 0.278 x C* + 1.117 x h°

The measured and predicted value graphs of the leaf NC prediction model developed from NDVI and color values are shown in Figure 3 using NDVI and all color parameters (L*a*b*C*h°).

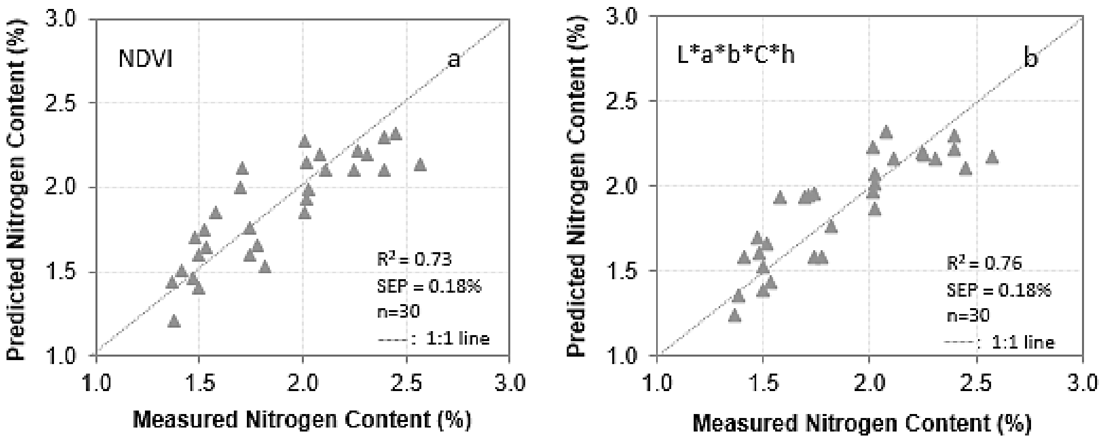

Figure 3. Measured vs. Predicted leaf N contents from the model with NDVI (a) & color values (L*a*b*C*h°) (b)

Some practical commercial optical measurement systems have been studied for the determination of nutrient and water stress of plants including chlorophyll meters, spectroradiometers, spectrophotometers, digital cameras, chromameters, fluorescence meter, NIR spectroscopy, etc. (Rodriguez and Miller, 2000; Keskin et al., 2004; Keskin et al., 2018). Similarly, some studies were carried out for the prediction of nutrient and water stress in turfgrass using spectrordiometers, chromameters, NIRS, and NDVI measurement systems (GreenSeeker, TCM500 NDVI Turf Color Meter, Crop Circle ACS-210). Chromameters and NDVI instruments have some advantages such as being easier to use, more practical and relatively inexpensive as compared to the spectroradiometers and NIRS systems. In the present study, two optical systems being a hand-held chromameter and a hand-held NDVI measurement system were compared for the prediction of nitrogen and water content of turfgrass.

Jiang et al. (2009) found a high correlation (r=0.77-0.81) between leaf water content and NDVI in perennial ryegrass. In the current study, a lower correlation was found (r=0.66) for the turfgrass which was a mixture of five different cultivars. In another study, Frank (2008) reported a coefficient of determination (R^2) of 0.71 for the water content estimation from NDVI for the hybrid bermudagrass, while in the present study, a lower value was determined (R^2=0.40). However, a higher value (R^2=0.69) was obtained with color values from the chromameter to estimate the water content.

Some studies were also carried out on using remote and proximal sensing systems to predict the turfgrass leaf nitrogen content. Mangiafico and Guillard (2007) found low to moderate relation (R^2=0.16-0.63) between Hue angle (h°) and N content of turfgrass leaves with a chromameter for the turfgrass with a mixture of different cultivars. In the current study, similar result was obtained for the prediction of nitrogen content (R^2=0.33) from hue value using chromameter (Table 4).

However, the use of multiple color parameters (L*C*h°) gave higher R^2 values (0.69) in the current study. On the other hand, in studies using hand-held NDVI devices, different results have been reported for the prediction of nitrogen content depending on the type of turfgrass and NDVI devices (R^2=0.19-0.85) (Frank, 2008; Moss and Bell, 2010; Caturegli et al., 2016; Guillard et al., 2016; Inguagiato and Guillard, 2016). In the present study, similar coefficient of determination (R^2) value between NDVI and N content was determined (0.73) (Table 4).

As a conclusion, the chromameter (R^2val=0.76; SEP=0.18 %) and the hand held NDVI device (R^2val=0.73; SEP=0.19 %) gave similar results for the prediction of the turfgrass leaf N content and hence, both devices can be used to evaluate the nitrogen content of turfgrass.

CONCLUSIONS

This study was conducted to investigate the usability of two different optical devices (hand-held NDVI meter and hand-held chromameter) in determining the nitrogen and water content of turfgrass. The following results were obtained:

- A high correlation was found among leaf nitrogen content (NC), water content (WC), NDVI and color values.
- It was determined that the NC of the turfgrass leaves could be predicted by the NDVI (R^2val=0.73; SEP=0.19 %) and the color values (L*a*b*C*h°) (R^2val=0.76; SEP=0.18 %).
- In the estimation of leaf WC; the chromameter (L*C*h°) (R^2val=0.69; SEP=3.67 %) was found to be better than NDVI meter (R^2val=0.40; SEP=5.07 %).

As a result; it was determined that the NC of turfgrass can be estimated with similar prediction performance using both hand-held NDVI meter and hand-held chromameter in a more objective and economic way.

ÖZET

Amaç: Geleneksel olarak çim bitkisinin azot (Aİ) ve su içeriği (Sİ) tahmini zaman alıcı, yorucu, fazla iş gücü gerektiren ve masraflı olan kimyasal laboratuvar analizleriyle belirlenmektedir. Bu çalışmanın amacı, iki farklı el tipi optik algılayıcının (GreenSeeker NDVI metre ve renk ölçer) çim bitkisinin azot ve su içeriğini değerlendirmedeki uygunluğunu incelemektir.

Yöntem ve Bulgular: Çalışmada 1 m x 1 m'lik altı adet çim parselinde değişken düzeyli azotlu gübre uygulaması yapılmıştır. NDVI ölçümleri arazide el tipi GreenSeeker NDVI ölçer ile gerçekleştirilmiştir. Biçme işleminden sonra, çim biçkilerinin renk değerleri laboratuvarda renk ölçer kullanılarak ölçülmüştür. Veriler korelasyon ve kısmi en küçük kareler regresyon (PLSR) analizi kullanılarak değerlendirilmiştir. Yaprak Aİ, Sİ ile NDVI ve renk değerleri arasında yüksek korelasyon bulunmuştur. Yaprak Aİ (%)'nin NDVI (R^2val=0.73, SEP=% 0.19) ve renk değerlerinden (L*a*b*C*h°) (R^2val=0.76; SEP=% 0.18) tahmin edilebileceği tepit edilmiştir. Ayrıca, Sİ (%)'nin NDVI (R^2val=0.40, SEP=% 5.07) ve renk değerlerinden (L*C*h°) (R^2val=0.69; SEP=3.67 %) daha düşük doğruluk ile tahmin edilebileceği belirlenmiştir.

Genel Yorum: Sonuç olarak; çim yaprağı Aİ'nin, NDVI cihazı veya renk ölçer kullanılarak daha objektif ve ekonomik bir şekilde makul hassasiyet ile tahmin edilebileceği tespit edilmiştir.

Çalışmanın Önemi ve Etkisi: Azot ve su içeriği analiz süresindeki azalma dikkate alındığında, çalışma sonuçlarının çim saha bakım sorumluları için faydalı olacağı değerlendirilmiştir. Ayrıca algılayıcılar ile yapılacak azot içeriği tespitinin çim alan bakım sorumluları tarafından kullanılması halinde daha çevre dostu bir yöntem olacağı düşünülmektedir.

Anahtar Kelimeler: Çim, uzaktan algılama, azot içeriği, su içeriği, NDVI ölçer, renk ölçer.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Berkant ODEMIS and Dr. Yurtsever SOYSAL for their support. Also they thank Aysel ARSLAN and Mustafa AKKAMIS for their assistance.

CONFLICT OF INTEREST

The authors declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

REFERENCES

ASABE (2012) Moisture Measurement-Forages. American Society of Agricultural and Biological Engineers, ANSI/ASAE Standarts, St Joseph, MI, S358.3, USA.

CAST (2019) Reducing the impacts of agricultural nutrients on water quality across a changing landscape. CAST Issue Paper Number 64. Council for Agricultural Science and Technology (CAST). 20 p.

Caturegli L, Corniglia M, Gaetani M, Grossi N, Magni S, Migliazzi M, Angelini L, Mazzoncini M, Silvestri N, Fontanelli M, Raffaelli M, Peruzzi A, Volterrani M (2016) Unmanned aerial vehicle to estimate nitrogen status of turfgrasses. PLoS ONE 11(6): e0158268.

EPA (2012) Frequently asked questions about nitrate and drinking water. United States Environmental Protection Agency (EPA). 2 p.

Esbensen KH (2009) Multivariate Data Analysis In Practice: An Introduction to Multivariate Data Analysis and Experimental Design. 5th edition. CAMO Inc. Corvallis, Oregon/USA.

Frank JH (2008) Detection of turfgrass stress using ground based remote sensing. MSc Thesis, University of Florida, Florida, US. 96 p.

Guillard K, Fitzpatrick RJM, Burdett H (2016) Can frequent measurement of normalized difference vegetative index and soil nitrate guide nitrogen fertilization of Kentucky Bluegrass. Crop Sci. 56: 827-836.

Inguagiato JC, Guillard K (2016) Foliar N concentration and reflectance meters to guide N fertilization for anthracnose management of Annual Bluegrass putting green turf. Crop Sci. 56: 3328-3337.

Hocaoglu T (2010) Evaluation of planning and design principles of golf courses in the context of landscape architecture: Gloria Golf Resort case. PhD Thesis, Ankara University, Ankara, Turkey. 151 p.

Jiang Y, Liu H, Cline V (2009) Correlations of leaf relative water content, canopy temperature, and spectral reflectance in Perennial Ryegrass under water deficit conditions. HortSci. 44(2): 459-462.

Kacar B (1994) Chemical analysis of plant and soil: III. Soil Analysis (In Turkish). Ankara Uni. Agric. Fac. Publ. No: 3, 735 p. Ankara

Kacar B, Inal A (2010) Bitki Analizleri (Plant Analysis – in Turkish). Nobel Publication Number: 1241, Ankara. pp 171-212.

Keskin M, Dodd RB, Han YJ, Khalilian A (2004) Assessing nitrogen content of golf course turfgrass clippings using spectral reflectance. Appl. Eng. Agric. 20: 851–860.

Keskin M, Han YJ, Dodd RB, Khalilian A (2008) Reflectance-based sensor to predict visual quality ratings of turfgrass plots. Appl. Eng. Agric. 24:855-860.

Keskin M, Karanlik S, Gorucu Keskin S, Soysal Y (2013) Utilization of color parameters to estimate moisture content and nutrient levels of peanut leaves. Turk. J. Agric. For. 37: 604-612.

Keskin M, Sekerli YE, Gunduz K (2016) Relationship between water content and color properties of chlorotic and non-chlorotic detached crop leaves. J. Agric. Fac. Uludag Univ. 30: 319-324.

Keskin M, Setlek P, Demir S (2017) Use of color measurement systems in food science and agriculture (in Turkish with abstract in English). International Advanced Researches and Engineering Congress, 16-18 November 2017, Osmaniye. pp 2350-2359. (in Turkish with abstract in English).

Keskin M, Sekerli YE, Gunduz K (2018) Influence of leaf water content on the prediction of nutrient stress in strawberry leaves using chromameter. Int. J. Agric. Biol. 20: 2103-2109.

Knudsen DG, Peterson A, Pratt PF (1982) Lithium, Sodium and Potassium. Methods of Soil Analysis, Part 2. Chemical and Migrobiological Properties. Agronomy Monograph No:9 (2 nd Ed.) ASA-SSSA, Madison, Wisconsin. USA.

Konica Minolta (2007) Colorimetry: How to Measure Color Differences. Konica Minolta Photo Imaging Inc., USA.

Mangiafico SS, Guillard K (2007) Cool-Season turfgrass color and growth calibrated to leaf nitrogen. Crop Sci. 47: 1217–1224.

Moss JQ, Bell GE (2010) Indirect Measurement of Creeping Bentgrass N, Chlorophyll, and Color for Precision Golf Green Management. 10th International Conference on Precision Agriculture Proceedings [CD-ROM], Denver, CO.

Olsen SR, Cole V, Watanabe FS, Dean LA (1954). Estimations of available phosphorus in soils by extractions with sodium bicarbonate. U.S. Dept. Of Agric. Cric. 939, USDA, Washington, DC.

Richards LA (1954) Diagnosis and Improvement of Saline and Alkaline Soils. Handbook. 60. US. Dept. of Agriculture.

Rodriguez IR, Miller GL (2000) Using near-infrared reflectance spectroscopy to schedule nitrogen applications on dwarf-type bermudagrasses. Agron. J. 92: 423–427.

Turkish Official Gazette (2004) Regulation on Protection of Waters Against Agricultural Nitrate Pollution (in Turkish). 18 February 2004, Number: 25377.