Journal of Ornamental Plants
Available online on: www.jornamental.iaurasht.ac.ir
ISSN (Print): 2251-6433 ISSN (Online): 2251-6441
Research Paper

Quality Assessment of Turfgrasses Using NTEP Method Compared to an Image-Based Scoring System

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Received: 16 May 2019 Accepted: 19 March 2020
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Abstract

The current methods of turfgrass evaluations are often based on human-based assessment methods. However, eliminating subjective errors from such evaluations is often impossible. This research compared the accuracy of human-based and digital image processing-based methods for quality assessment of turfgrasses. Four turfgrass plots were evaluated using the two mentioned methods. In the human-based method, 20 evaluators (10 women and 10 men) and in the image-based method, a digital camera with an artificial and controlled light source were used. This experiment for the first time evaluated the two qualitative characteristics of turfgrass texture and weed growth tolerance using a specific image processing-based technique and the common human-based evaluation method. Further, total coverage, color, and living coverage of the turfgrasses were compared with the two methods. The results of the human-based assessment method showed a wider range and higher standard deviations than that in the image processing method, which seems to be due to the differences between the human's evaluators and errors caused by the human mind. The results also emphasized the accuracy and ease of application of the image-processing-based method. This outcome can have applications for developing a mechanized system for turfgrass quality evaluation across the world.

Keywords: Digital photo assessment, Greenspace management, Human evaluation, Lawn, Quality factors.

INTRODUCTION

Evaluation of turfgrass qualitative characteristics is of great importance due to the important role of the turfgrasses in green space development (Watkins *et al*., 2011). Currently, the most common evaluation method for turfgrass quality is the conventional method which is based on human-based assessment methods in a visual manner (Mintenko *et al*., 2002; Zhang *et al*., 2017). In the human-based assessment method, attempts have been made to capture all the turfgrass qualitative features in a ranking approach. Some standards and protocols have been defined for the conventional method from which the method briefly called the NTEP (National Turfgrass Evaluation Program), developed by Morris and Shearman (2000), is the most common one. In NTEP, the visual attributes of the turfgrasses are scored by trained assessors, with gender equality of men and women which rank the turfgrasses from 1 to 9, with the number 1 indicating the failing or dead turfgrass, and number 9 representing the best quality turfgrass. The turfgrasses scored 6 to 9 represent acceptable level of turfgrass quality factors such as color, texture, total coverage (Keskin *et al*., 2008; Morris and Shearman, 2000; Fu *et al*., 2004) or even their diseases and nutrition deficiency or breeding resistance assessments (Jayasinghe *et al*., 2019). There are also records of studies in which image processing techniques can provide insight into the management practices of orchards (e.g. Santesteban *et al*., 2017) and grasslands (Bueren *et al*., 2015). In some studies also, a scoring range from 1 to 10 has also been reported for the evaluation (Rodriguez and Miller, 2000). Some researchers have reported that although some turfgrass characteristics can visually be recognized (Landschoot and Mancino, 2000), there is still a need for the development of turfgrass assessment techniques based on proven growth responses that are biologically identifiable (Jayasinghe *et al*., 2019). It seems that although rankings of visual characteristics by human are acceptable when the characteristics are compared with each other and it is possible to obtain inter-related information from such assessments, these data may, however, be very variable and difficult to repeat as they are mainly affected by the evaluators' views. Therefore, the final results may be questionable because of the subjective nature of the responses (Jayasinghe *et al*., 2019). For example, covering is one of the important characteristics in turfgrasses especially in the turfgrass establishment stage. In general, obtaining knowledge on the effecting factors on turfgrass establishment is very important because the inappropriate or delayed establishment of the lawn can cause significant problems. Unfortunately, the studies on coverage and establishment of the turfgrasses in field conditions are often challenging. This is because precise quantification of this factor in the field in the real plots is costly and requires a significant amount of time and labor work (Karcher and Richardson, 2005) as the turfgrass scientists use visual rating (VR) to assign a numerical value to a turfgrass. However, the rating are considered subjective as they lack quantifiable numerical values and are considered subjective. Therefore, there is often inconsistency among evaluators in the interpretation of rating criteria (Hoyle *et al*., 2013; Zhang *et al*., 2017). Color is also one of the key attributes in the aesthetic performance of the turfgrasses and a good indicator of its water and nutrients status. Therefore, color is often an important characteristic of the quality assessment of turfgrasses and there have been several studies on developing objective methodologies for quantifying turf color differences (Zhang *et al*., 2017).

Efforts have been made to further enhance the NTEP method, for example, in a survey of the National Turfgrass Evaluation Program conducted by sponsored university scientists with an aim to further enhance the protocols and standards as there were significant disagreements even among the scientists about the scoring system. Finally, the most accepted evaluation methods for NTEP were assigned to be based on idealized images of the turfgrasses (Krans and Morris, 2007). Therefore, considering that the visual assessment-based methods are mainly subjective and the results may be contradictory, some researchers have examined the accuracy of the image processing-based techniques (Karcher and Richardson, 2003). Casadesús *et al*. (2005) confirmed that even a common digital camera could be used as a convenient tool for collecting the land data about turfgrasses and possibly other plants. Other researchers also found that the image processing methods for assessing visual characteristics are precise and reliable (Lock *et al*., 2004; Crusiol *et al*., 2019), and these methods can be used as improved, effective and targeted methods to describe some qualitative characteristics including color (Zhang *et al*., 2017) and total coverage (Karcher and Richardson, 2003; 2005) in turfgrasses. Karcher and Richardson *et al*. (2003) stated that image processing is an effective method for evaluating the percentage of green turfgrasses in the plots. This method plays a role in detecting small differences in total coverage of the turfgrasses. Bell *et al*. (2009) reported that less time is needed for the turfgrass evaluation using image processing techniques, and some characteristics that cannot be easily detected by human beings can be easily evaluated by this method.

The purpose of this study was to compare two methods of turfgrass evaluation including the common visual assessment by a human and the assessment using digital image processing. The possibility of evaluating three turfgrass attributes of total coverage, color and living coverage by the two methods was assessed. The two important factors of leaf texture and weed tolerance were also assessed by the image processing technique and by its corresponding human-based NTEP scoring method. Accordingly, the following hypotheses were examined: 1. Evaluation by image processing method has more accuracy than the human-based method; 2. In addition to total coverage and color, the characteristics of texture, living vegetation cover, and tolerance to weed growth can also be evaluated using the image processing method.

MATERIALS AND METHODS

This research was carried out in the research fields of the Faculty of Agriculture, Ferdowsi University of Mashhad, Iran (59° 38 ‘East and 36° 16’ N, elevation 989 m, average annual precipitation 255.2 mm, maximum temperature: 22°, minimum temperature: 8.9°) during autumn, 2014 till late summer, 2015. To conduct the research, 4 plots were planted in equal dimensions of 0.5 m ´ 2 m. The plots were planted in autumn after plowing and leveling the land. Then, the sports lawns, Barnburgh Netherlands, were planted directly in the plots and were covered with soil. In early summer, when the turfgrasses were reached to the initial stage of development, 20 trained evaluators (10 females and 10 males), were asked to rank the characteristics of color, total coverage, texture, tolerance to weeds and living coverage visually and on the basis of the NTEP scoring system 1 to 9. Based on this ranking method, for each characteristic, number 1 is the weakest quality grade and number 9 is the highest quality (Morris and Shearman, 2000). The rating range for the characteristics is as follows:

Dark green color = 9 and yellowish-brown color = 1

Total Coverage: Complete coverage of the desired level = 9 and the surface completely free of coverage=1

Texture: Thin and subtle texture= 9 and coarse and rough texture = 1

Living coverage: Completely alive and green grass coverage = 9 and completely yellow or brown grass coverage = 1

Weed tolerance: Weed growth was not at the desired level = 9, and the full coverage of the target area with weed = 1

In the next step, using a digital camera (Nikon Coolpix PS560, Nikon Inc., Japan) with a specifically designed chamber, some images were taken from the studied plots.

Non-uniform and varying illumination such as natural illumination was proven to be a source of error in the analysis of color (Allred and Olkkonen, 2013; Bianco *et al*., 2015). Therefore, a portable imaging box with controllable artificial lighting was designed and constructed for acquiring the digital images of various plots of turfgrass at varying quality. The camera was placed on top of the box, looking downwards to the turfgrass through a hole cut on the top of the box (Fig. 1(. The camera was placed 40 cm above the ground. The resolution of the images was 3264×2448. A rectangular marker frame of the size of (50 cm × 60 cm) was placed on a region inside the box when taking the images in order to facilitate the selection and cropping of a specific sub-region of the area (Fig. 2).

The images were taken between mid-morning and early afternoon. Then, the taken images were processed in Matlab programming software (Mathworks Inc., US, v2015b). The images were first converted to matrices in this software and the mathematical operations were applied to extract the desirable features from these matrices.

From each image, first, the weeds region was specified from the image (Fig. 3a and b). The color of the turfgrass was extracted from each pixel inside the selection area after excluding the pixels associated with weed regions (Fig. 3c).

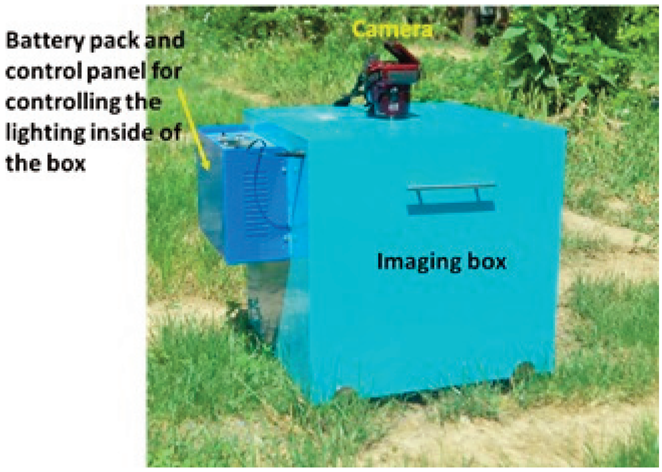

Fig. 1. Imaging box and its main parts constructed for this study.

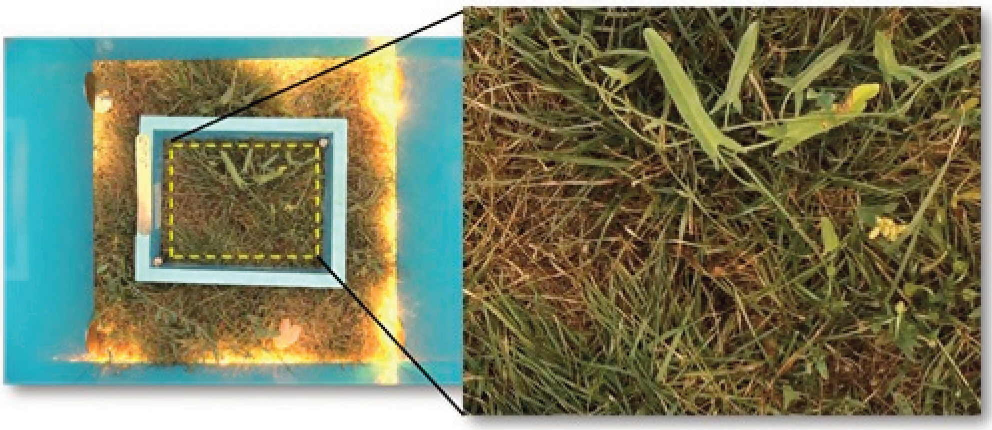

Fig. 2. Selection of the specific region inside the frame and the box.

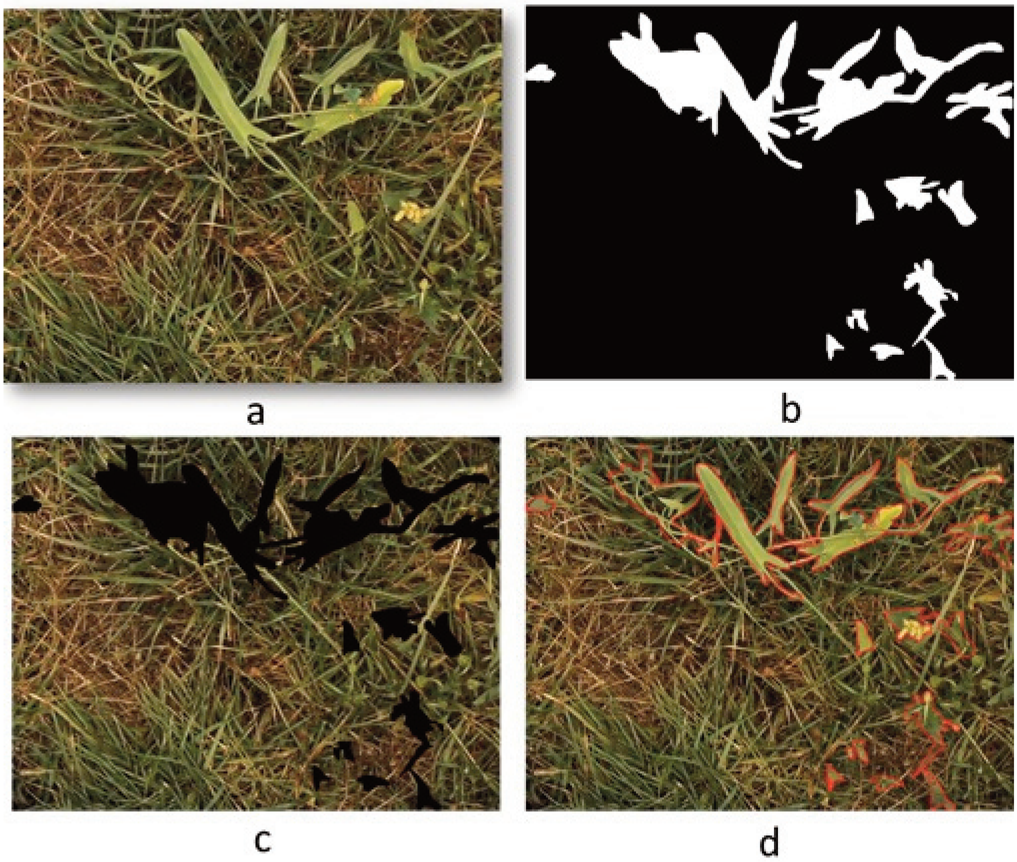

Fig. 3. The processing steps on images: a) The selection of the turfgrass and weeds; b) The binary mask showing the weeds as white and everything else as black; c) The turfgrass region after removing the weed region from the selection; d) An image with displayed weed regions with red boundaries.

The values extracted from the turfgrass pixels were then averaged. The color features were red, green, blue components from the RGB color model. Hue, saturation, and brightness from HSI color space. Hue is an angle on a continuous circular scale from 0 to 360° (0° = red, 60° = yellow, 120° = green, 180° = cyan, 240° = blue, 300° = magenta), saturation is the purity of the color from 0 % (gray) to 100 % (fully saturated color), and brightness is the relative lightness or darkness of the 79 color from 0% (black) to 100% (white). Other color components were L, a* and b from L, a*, b* color space. In L*a*b*, L or lightness, goes up and down and it consists of white to black; a* changes from cyan color across to magenta/red color and b* represent a color change blue to yellow. Among all these color components, hue, a*, b* seemed to define the true color of an object and therefore to be more appropriate for describing the color in turfgrasses. Hue, which is similar to human color perception used to communicate color ideas, refers to pure color in terms of "green-ness", "redness", e.t.c. (Russ, 2016). The values of this color component, which is measured as an angle on a continuous circular scale, ranges from 0° to 359° (0° = red, 60° = yellow, 120° = green, 180° = cyan, 240° = blue, 300° = magenta). The color parameter a* extends from green (-1) to red (+1) and the b* parameter extends from blue (-1) to yellow (+1). Both a* and b* seem to be suitable in describing the color in turfgrasses. A green turfgrass has minus a* and relatively close to zero b*. A green-yellow turf has minus a* and positive b* (Fig. 4).

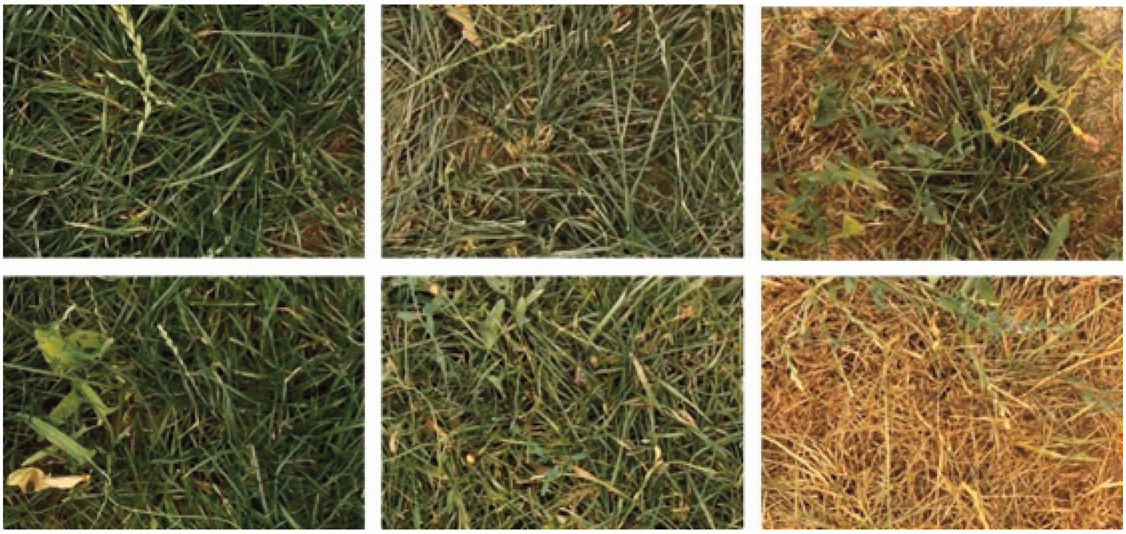
Fig. 4. Variations of colors in turfgrasses with different conditions.

The color changes across the turfgrass regions were determined in terms of the standard deviation of the pre-extracted color components from the pixels in the selection area.

The percentage of weed coverage was measured as the ratio of the number of pixels associated with the weeds to the total number of the pixels in the selection area (Equation 1).

$$Weed\ cover\ (\%) = \frac{Number\ of\ weed\ pixels}{Width\ \times Height\ of\ the\ selection\ area\ (pixels)} \quad \text{Equation 1}$$

In this experiment, to facilitate the comparison of the data achieved from Matlab software with the data achieved by 1~9 human scoring evaluation, the data obtained by the software were normalized to this domain using the following formula:

$$\text{Green cover} = \text{Green cover percentage} \times \frac{9}{10} \quad \text{Equation 2}$$

$$\text{Color} = \frac{Hue \times 9}{(Hue_{max} - Hue_{min})} \quad \text{Equation 3}$$

Calibration of the color indices was made by 10 experts using a range of 20 images of color tiles ranging from a greenish-yellow color to dark bluish-green. Based on this calibration, the equivalent hue value for the dark bluish-green color, which is equal to the score 9 in NTEP ranking system, was obtained to be 0.425 and for the greenish-yellow color, which is equal to the score 1 in NTEP ranking system, was determined to be 0.129.

The values of the texture features extracted from the images were also normalized to the range of 1-9, so the values to be comparable with those given by the visual assessors. These features and their corresponding parameters in NTEP are given in table 1.

The frequency of each parameter was drawn in Excel (V. 2016, Microsoft Co.) for the two methods of the turfgrass evaluation, i.e. the human-based and the image processing-based methods, and the graphs were compared and described.

Table 1. Image-based features and their corresponding NTEP parameters.

Image based feature	NTEP parameter
(√(1- smoothness ×9)/100	Texture
(the weed area – bare soil area) × 9/100	Weed tolerance
100% total coverage – the percentage of yellow color achieved by the software – the percentage of necrosis achieved by the software) × 9)/100	Living coverage

RESULTS AND DISCUSSION

In this experiment, the characteristics of the turfgrass total coverage, color and living coverage and also texture and weed growth tolerance were evaluated using the image processing method and the human-based observation method. The novelty of this project was to introduce the latter two important parameters in the quality assessment of the turfgrasses using the image-processing techniques and to introduce a technical method for their evaluation in the field which, to the best of our knowledge, has not been addressed previously. The texture is one of the important qualitative characteristics of the turfgrasses, which plays a significant role in its aesthetic performance. The lawn texture is determined by the width of the leaf, and the narrower the leaf, the finer the turfgrass texture would be (Morris and Shearman, 2000). Weed growth tolerance attribute also indicates how uniform the lawn has been and how it has contributed to the suppression of the weeds (Morris and Shearman, 2000).

In the conventional evaluation method in turfgrass management, these attributes are visually determined by human assessors (e.g. Mintenko *et al*., 2002; Zhang *et al*., 2017). However, these visual assessments are generally subjective and do not provide a rigorous and accurate means of providing lawn quality (Keskin *et al*., 2008). Some researchers have previously attempted to quantify some of the qualitative parameters based on non-human evaluation methods such as digital image analysis or optical sensors for measuring density (Bell *et al*., 2009), coverage (Bunderson *et al*., 2009), green vegetation (Laliberte *et al*., 2007), color (Bunderson *et al*., 2009; Landschoot and Mancino, 2000; Karcher and Richardson, 2003; Casadesús *et al*., 2005). In some of these research works, there were drawbacks; for example, in an assessment by Bunderson *et al*. (2009) the machine was unable to detect soil color from the yellow color plants. Also, when only living coverage of plants was evaluated, detection of the target plants from the weeds was not possible and these caused errors in the measurements using the image processing techniques.

In this experiment, there are some points to consider in the results obtained from the two characteristics of living coverage and weed growth tolerance. In the human-based assessment method, the evaluators scored the total coverage of the turfgrasses in the studied area in the range of 1 to 9, 1 representing the least coverage and 9 representing the most complete coverage according to the NTEP scoring system. However, in the image processing method, the amount of the total coverage is calculated as follows:

$$\text{Total coverage (\%)} = \text{Total area (\%)} - \text{bare soil area (\%)} - \text{weed area (\%)}$$

Therefore,

if: Soil area (%) = 0

Then,

Total coverage (%) = 100 – weed area (%) – bare soil area (%)

and; weed area (%) = 100 – total coverage (%)

Therefore, weed growth tolerance (%) = 100 – weed area (%)

Therefore, if the area of the soil is zero:

Total coverage (%) = weed growth tolerance (%)

The above-mentioned finding was confirmed by the results obtained from processing the images and deriving two parameters of total coverage and “weed growth tolerance”. Fig. 5, showing the frequency of these two parameters, confirm that these are in fact the same, as it was proven theoretically. However, the results by the human-based evaluation method showed that these parameters were seen differently by human subjects (Fig. 5c, d).

In general, comparing the frequencies of each measurement in the graphs, the average and the standard deviation of the scores in the NTEP system and the image processing system, it is derived that the changes of the scores in the image processing system are due to the differences between the various blocks or parts of the field of the turfgrass. This means that if we take images several times from a specific part of a plot or field, the image processing algorithm results in relatively the same figure. Therefore, in the image processing method, evaluation numbers (scores) can be more precisely. While the evaluation scores given by human assessors are broader in range and the numbers are very subjective and very different from one evaluator to the other (Table 2). Also, comparing the differences between the standard deviations of the characteristics obtained from both methods in table 2 indicate that such difference for weed growth tolerance (1.02) is the highest among the corresponding numbers for the other characteristics. Therefore, it is considered that the possibility of errors by human evaluators for this characteristic is the highest. Therefore, it is recommended that other more precise methods are considered for evaluating this characteristic in turfgrasses. For the characteristics of total coverage, color, living coverage and texture, the differences between the standard deviations of the scores of the image processing method and the human-based evaluation method were found to be much smaller, respectively (Table 2, Fig. 6). Comparing the differences between the standard deviation of human-based evaluation and image-based evaluation for the five measured factors, it can be seen that the number for texture (0.32) is the lowest and for weed growth tolerance is the highest (1.02) (Table 2, Fig. 6).

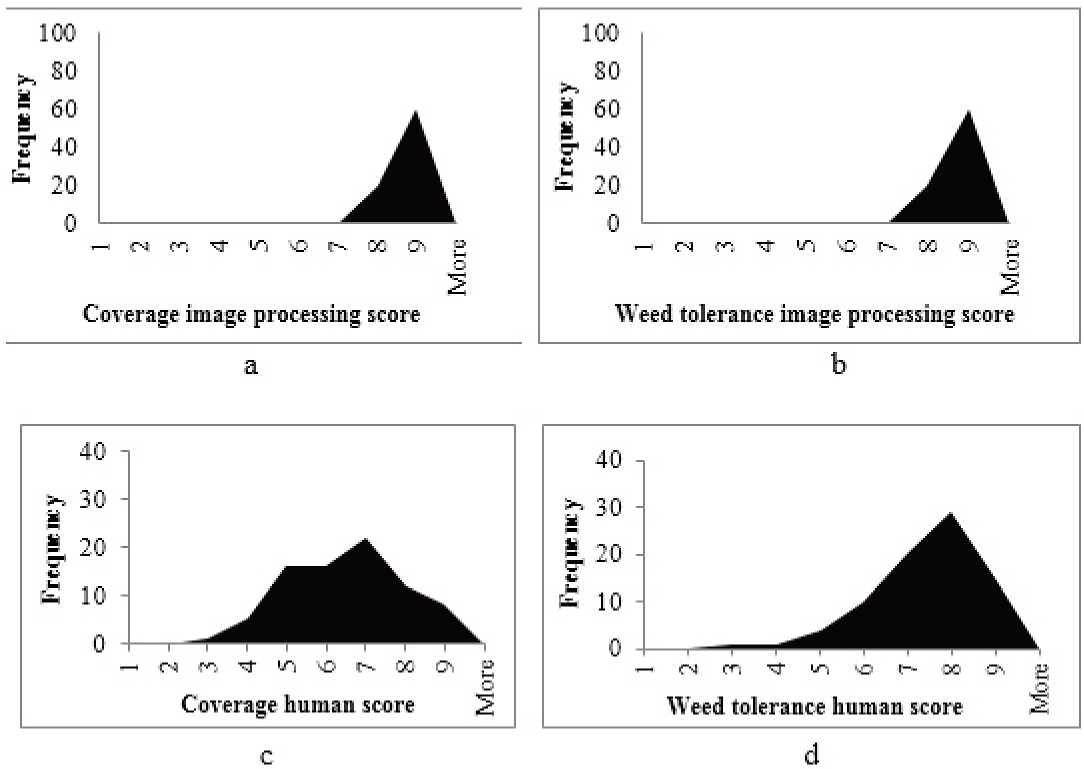

Fig. 5. The frequency of the obtained scores in the image processing method for, a) Total coverage, b) Weed growth tolerance, and human-based evaluation for, c) Total coverage, and d) Weed growth tolerance.

Accordingly, it seems that there is more confidence in the precision of the scores for the human-based evaluation method for the characteristics of turfgrass texture than the scores given to the other characteristics by human evaluators. Our results in texture recognition by a human were not confirmed in previous research. However, Richardson *et al*. (2003) and Zhang *et al.* (2017) confirmed more precision human-based evaluation on color, and Karcher and Richardson (2003) on total coverage of the turfgrasses. Such controversial results among the previous researchers seem to be the results of weak or random recognitions of human-based evaluation methods. In each case, the existence and the occurrence of mental and subjective errors by human evaluators, sometimes raise questions on the analysis of variance related to these measurements (Karcher, 2000). The point here is that visual assessment of the turfgrass based on human-induced method is highly dependent on individual thinking and perception and may be different in a given context on a specific topic even if the assessment is made on a fixed measurement point on the turfgrass (Hoyle *et al*., 2013; Zhang *et al*., 2017).

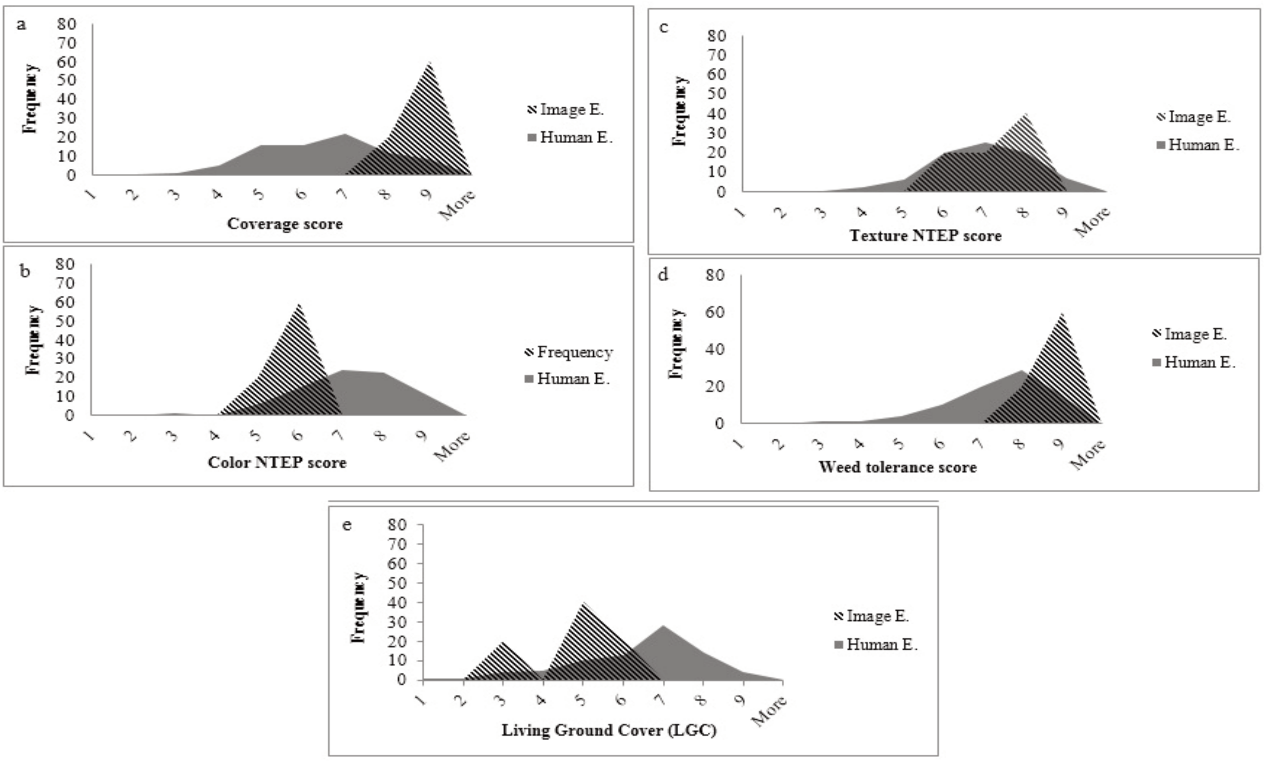

Fig. 7. The frequency of the scores obtained by human-based NTEP scoring system (Human E) compared with image processing-based system (Image E) for the characteristics of total coverage (a), color (b), texture (c), tolerance to weed growth (d), living coverage (e).

Table 2. Comparison of the averages and standard deviations of the human-based evaluation and image-based evaluation methods for quality characteristic assessment of the turfgrasses.

Quality characteristics (scores 1-9)	Standard deviation		The difference between the standard deviation of human-based evaluation and image-based evaluation	Average	
	Human-based evaluation	Image-based evaluation		Human-based evaluation	Image-based evaluation
Total coverage	1.45	0.50	0.95	6.51	8.72
Color	1.23	0.50	0.73	7.46	5.75
Texture	1.18	0.86	0.32	6.95	7.15
Weed growth tolerance	1.32	0.30	1.02	7.30	8.76
Living coverage	1.66	1.25	0.41	6.34	4.75

Comparing the results in table 2, it can be seen that in evaluation by the image processing-based method, the scores obtained for all the measured characteristics are closer to the averages for the scores, but in the human-based assessment method, the scores have a wider range and, in fact, usually far from the average number. These conditions have been discussed by the previous researchers. For example, Swanson and Cohen (2003) reported that physical conditions of the human evaluators including visual differences in the structure of the eyes and the nervous system of the individuals may affect the accuracy of the evaluation. The differences in color vision or visual errors in observing an image by different people have been previously confirmed (Swanson and Cohen, 2003).

Other factors such as age, gender, culture and nationality and the experience and knowledge of the evaluators (Abramov *et al*., 2012; Nazemi Rafi *et al*., 2020) can also be the sources of variation in human-based evaluation methods which has been controlled in this experiment by selection of relatively similar age group and nationality people in this experiment. Further, the proportion of female/male evaluators was the same. Also, all of the evaluators were trained similarly about NTEP by an instructor. Further, environmental conditions, when and where the assessment is made, the sky is clear or cloudy, and how are the light intensity and angle (Swanson and Cohen, 2003), are some of the other factors affecting the individual's assessment of the turfgrasses.

Considering the above-mentioned points and in conditions where many variables influence human-based turfgrass assessment method, obtaining average scores that provide the most accurate picture of the grass quality, and gathering people with optimum mental, physical and educational conditions for evaluations is costly, time-consuming and in some cases less possible. Therefore, creating an image-based evaluation system in which light intensity and its angles can be adjusted and uniformed in any circumstances, and also the above-mentioned human-based errors and factors cannot affect can provide a more accurate and less costly evaluation of the visual attributes in turfgrasses. Based on our results, the image-based assessment method compared with the human-based method could effectively eliminate inherent errors and biased evaluations that are usually associated with subjective classifications. In addition, as the images used in the image processing software have been taken under similar optical conditions (with the source of artificial light in the closed box), it facilitates fare comparisons of lawn colors among different researchers and practitioners at different times and places. These findings are consistent with the findings of Leinauer *et al*. (2014), Hoyle *et al*. (2013), Zhang *et al*. (2017), and Jayasinghe *et al*. (2019).

Overall, we can conclude that human-based visual ratings are subjective, time-consuming and inconsistent methods for turfgrass assessment while image-based techniques can provide the researchers and practitioners with highly consistent, less-subjective, easy and real-time quantifiable ratings. These techniques, consequently, open a new window with higher accuracy, efficiency, and repeatability in experimental and landscape-scale studies on turf grass management.

ACKNOWLEDGEMENT

This research was supported by Ferdowsi University of Mashhad, under grant number 40088, for which we are grateful.

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How to cite this article:

Kazemi, F., Golzarian, M. and Nematollahi, F. 2020. Quality assessment of Turfgrasses using NTEP method compared to an image-based scoring system. *Journal of Ornamental Plants,* 10(3), 177-178.

URL: http://jornamental.iaurasht.ac.ir/article_675375_d479fcdcf8cef90a749de9cc382599d6.pdf