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Batch Analysis of Digital Images to Evaluate Turfgrass Characteristics

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ABSTRACT

Techniques using digital image analysis have been recently developed to evaluate turfgrass stands for percent green cover and average color. Manually analyzing digital images may become cumbersome and tedious if turf field trials contain many plots or if images are collected at frequent intervals for analysis. The objective of the following work was to develop a user-friendly macro capable of automated batch analysis of an unlimited number of digital images. A macro named "Turf Analysis" was written to batch analyze images using SigmaScan Pro software. The macro, which requires less than 1 min of manual execution, performs percent cover and/or color analysis on an unlimited number of images and automatically saves the results into a spreadsheet file. The macro is freely available to download.

Historically, field experiments investigating turfgrass have been evaluated by visual ratings. Although relevant information may result from such evaluations, final inferences may be questionable because of the subjective nature in which the data were collected (Horst et al., 1984). Recently, digital image analysis techniques have been developed that allow researchers to objectively measure turfgrass characteristics such as percent ground cover (Richardson et al., 2001) and turf color (Karcher and Richardson, 2003). The analysis techniques utilize SigmaScan Pro software (SPSS, 1998) to select pixels representing turf within an image so that they may be further processed for the evaluation of interest. The ground cover techniques allow researchers to accurately measure parameters such as establishment rates, disease incidence, and recovery from injury or dormancy. The color methods allow for comparison of genetic color among varieties, as well as responses to fertility or other management variables.

Under normal use of SigmaScan Pro, each image must be processed manually, which may take several minutes and limit large-scale use of the techniques. However, SigmaScan Pro is enabled with a macro language so that users may automate software processes. The development of a user-friendly, easily attainable macro to batch analyze large numbers of turf images should broaden the use of digital image analysis techniques and result in more objective evaluations of turfgrass trials. The objective of the following work was to develop such a macro.

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MATERIALS AND METHODS

A SigmaScan Pro macro named "Turf Analysis" was written by the authors (in visual basic for applications language) that is capable of batch analyzing turf images. The macro may be freely downloaded from the University of Arkansas web site: http://www.uark.edu/campus-resources/turf/turfmacro; verified 11 March 2005. SigmaScan Pro must be installed on the same PC containing the macro for proper operation.

Before executing the macro, the images to be analyzed must all share the same file extension and be named so that they share a root name and each image contains a unique, consecutive number at the end of the file name (example: Plot01.jpg, Plot02.jpg, Plot03.jpg…). Most digital image archiving software packages that are sold with digital cameras are capable of naming or renaming image files similar to the format described above. In addition, there are many freeware file renaming software packages currently available for download (Nonags.com, 2004). The macro will function correctly with or without leading zeros at the end of the file name and with any image file extension that SigmaScan Pro recognizes (.jpg,.bmp,.tif, etc…).

The macro is executed by selecting "File > Open > Macro" from within SimgaScan Pro. Upon selecting the "Turf Analysis" macro file and then pressing the "F8" key to begin macro execution, a dialog box named "Turf Analysis Settings" is opened (Fig. 1) to customize the macro settings for a specific analysis of a batch of images.

Image Files Information

The parent folder, shared root name of the images, image file extension, and the first and last file numbers are defined within the "Image Files Information" box. If the image files contain leading zeros, these should be included in the text boxes defining the first and final image numbers. In the example analysis settings shown in Fig. 1, a batch of 489 images of tall fescue (*Festuca arundinacea* L.) plots diseased with brown patch (*Rhizoctonia solani* Kühn) is to be analyzed. The files are named "Plot001.jpg" through Plot489.jpg" and are located in the folder, "C:\Documents and Settings\KARCHER\My Documents\Research\NTEP Tall Fescue\Brown Patch Images."

Color Analysis

An analysis of turf color will be performed on the images if the "Perform color analysis" (Fig. 1) checkbox is selected. Either entire images may be used to determine average color or a color threshold may be used to determine average color from selected pixels. In the example analysis settings, color analysis of the brown patch images will be performed using threshold settings so that only green pixels (representing nondiseased turf) are used to calculate average color. The default macro settings perform a color analysis using the entire image to calculate average color.

Cover Analysis

An analysis of percent turf cover will be performed on the images if the "Perform cover analysis" (Fig. 1) checkbox is selected. Three options are available for determining the total

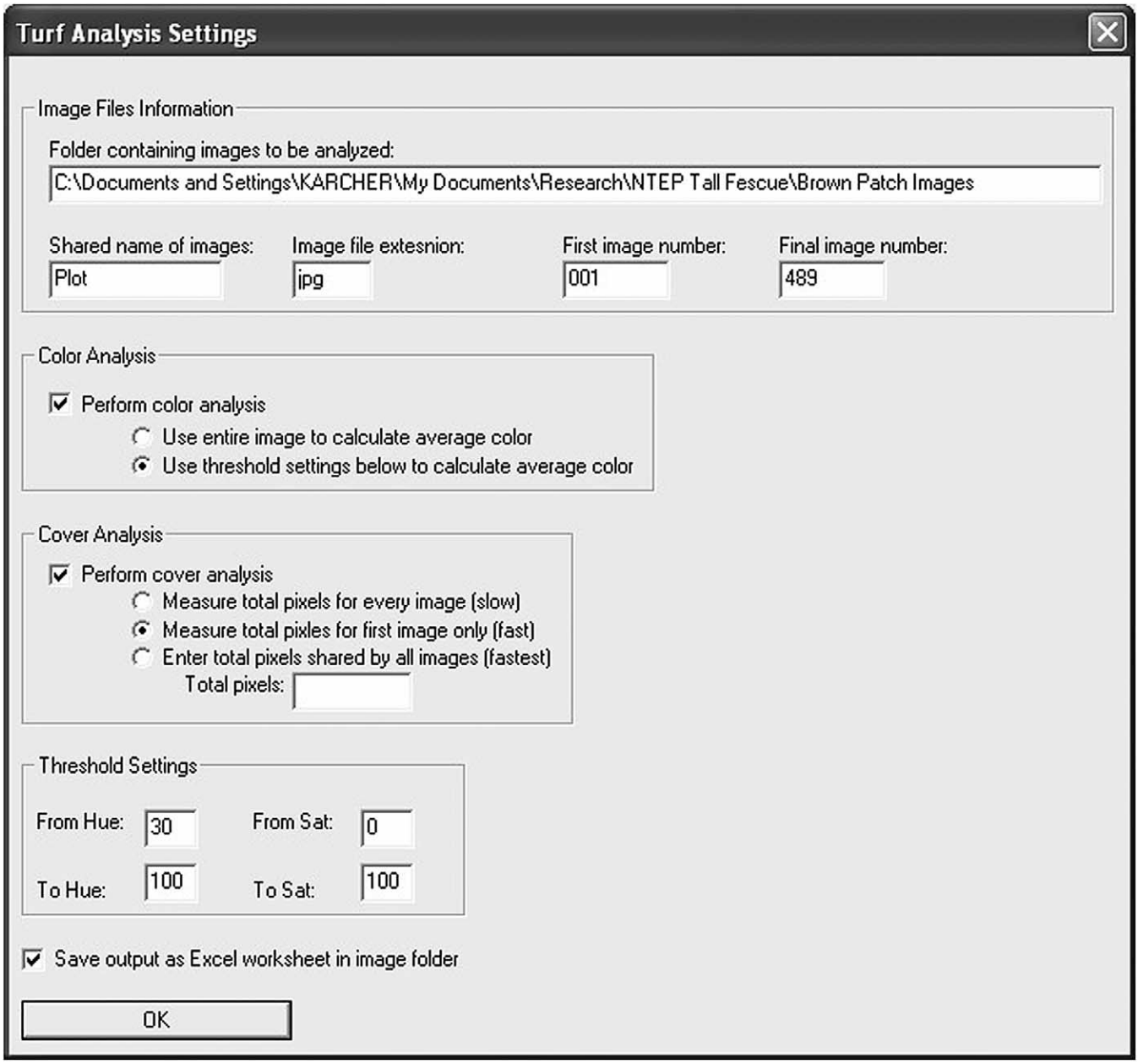


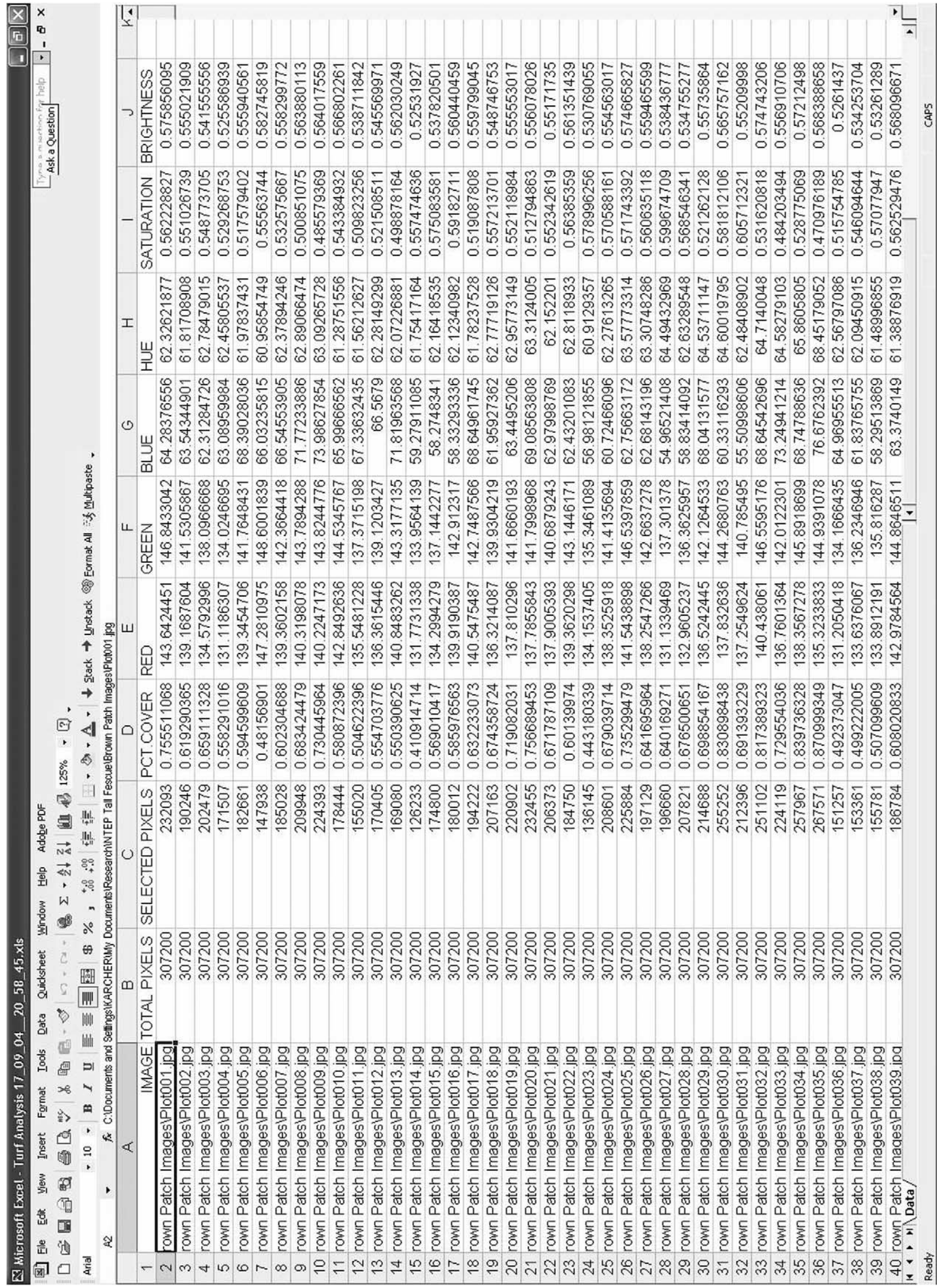
Fig. 1. User dialog box used to adjust the image analysis settings before executing the "Turf Analysis" macro.

number of pixels in each image, which is subsequently used to calculate percent cover: The first option is to separately measure the total pixel number for each image, which is the slowest option, but is necessary if total pixel numbers vary among the images within a batch. This would be the case if pictures within a batch were taken with different resolution settings or if images were cropped before analysis. The second option is to only measure the total pixel number for the first image and use that value as the total pixel number for all subsequent images, which is appropriate if all images within an analysis batch were taken with identical camera settings, not cropped, and thus share the same number of total pixels. The third and fastest option, which may be used if all images share the same number of total pixels, is to manually enter the shared total pixel number in the text box provided. The default macro settings analyze images for percent cover and only measure the first image to determine total pixel numbers.

Threshold Settings

The "Threshold Settings" box (Fig. 1) is used to adjust the hue and saturation levels that are used to select pixels representing green turf for the cover and color analyses. Before executing the macro, it is important to open a few representative images in SigmaScan Pro and select "Image > Threshold > Color Threshold" to determine the precise hue and saturation levels that will select the pixels of interest within the images. The appropriate threshold settings will vary depending on factors such as turf species and variety, management practices, light conditions present when images were collected, and camera model and settings. The default settings are hue levels from 30 to 100 and saturation levels from 0 to 100.

If the "Save output as Excel file in image folder" box (Fig. 1) is checked, the macro output will be automatically saved to the folder containing the batch of images to be analyzed. The



	A	B	C	D	E	F	G	H	I	J
1	IMAGE	TOTAL PIXELS	SELECTED PIXELS	PCT.COVER	RED	GREEN	BLUE	HUE	SATURATION	BRIGHTNESS
2	rown Patch Images\Plot001.jpg	307200	232093	0.755511068	143.6424451	146.8433042	64.28376556	62.32621877	0.562228827	0.575856095
3	rown Patch Images\Plot002.jpg	307200	190246	0.619290365	139.1687604	141.5305867	63.54344901	61.81708908	0.551026739	0.555021909
4	rown Patch Images\Plot003.jpg	307200	202479	0.659111328	134.5792996	138.0966668	62.31284726	62.78479015	0.548773705	0.541555556
5	rown Patch Images\Plot004.jpg	307200	171507	0.558291016	131.1186307	134.0246695	63.08959984	62.45805537	0.529268753	0.525586939
6	rown Patch Images\Plot005.jpg	307200	182661	0.594599609	139.3454706	141.7648431	68.39028036	61.97837431	0.517579402	0.555940561
7	rown Patch Images\Plot006.jpg	307200	147938	0.48156901	147.2810975	148.6001839	66.03235815	60.95854749	0.55563744	0.582745819
8	rown Patch Images\Plot007.jpg	307200	185028	0.602304688	139.3602158	142.3664418	66.54553905	62.37894246	0.532575667	0.558299772
9	rown Patch Images\Plot008.jpg	307200	209948	0.683424479	140.3198078	143.7894288	71.77233886	62.89066474	0.500851075	0.563880113
10	rown Patch Images\Plot009.jpg	307200	224393	0.730445964	140.2247173	143.8244776	73.98627854	63.09265728	0.485579369	0.564017559
11	rown Patch Images\Plot010.jpg	307200	178444	0.580872396	142.8492636	144.5345767	65.99666562	61.28751556	0.543384932	0.566802261
12	rown Patch Images\Plot011.jpg	307200	155020	0.504622396	135.5481228	137.3715198	67.33632435	61.56212627	0.509823256	0.538711842
13	rown Patch Images\Plot012.jpg	307200	170405	0.554703776	136.3615446	139.1203427	66.5679	62.28149299	0.521508511	0.545569971
14	rown Patch Images\Plot013.jpg	307200	169080	0.550390625	140.8483262	143.3177135	71.81963568	62.07226881	0.498878164	0.562030249
15	rown Patch Images\Plot014.jpg	307200	126233	0.410914714	131.7731338	133.9564139	59.27911085	61.75417164	0.557474636	0.52531927
16	rown Patch Images\Plot015.jpg	307200	174800	0.569010417	134.2994279	137.1442277	58.2748341	62.16418535	0.575083581	0.537820501
17	rown Patch Images\Plot016.jpg	307200	180012	0.585976563	139.9190387	142.912317	58.33293336	62.12340982	0.59182711	0.560440459
18	rown Patch Images\Plot017.jpg	307200	194222	0.632233073	140.5475487	142.7487566	68.64961745	61.78237528	0.519087808	0.559799045
19	rown Patch Images\Plot018.jpg	307200	207163	0.674358724	136.3214087	139.9304219	61.95927362	62.77719126	0.557213701	0.548746753
20	rown Patch Images\Plot019.jpg	307200	220902	0.719082031	137.810296	141.6660193	63.4495206	62.95773149	0.552118984	0.555553017
21	rown Patch Images\Plot020.jpg	307200	232455	0.756689453	137.7855843	141.7998968	69.08563808	63.3124005	0.512794863	0.556078026
22	rown Patch Images\Plot021.jpg	307200	206373	0.671787109	137.9005393	140.6879243	62.97998769	62.152201	0.552342619	0.55171735
23	rown Patch Images\Plot022.jpg	307200	184750	0.60139974	139.3620298	143.1446171	62.43201083	62.8118933	0.56385359	0.561351439
24	rown Patch Images\Plot023.jpg	307200	136145	0.443180339	134.1537405	135.3461089	56.98121855	60.9129357	0.578996256	0.530769055
25	rown Patch Images\Plot024.jpg	307200	208601	0.679039714	138.3525918	141.4135694	60.72466096	62.27613265	0.570588161	0.554563017
26	rown Patch Images\Plot025.jpg	307200	225884	0.735299479	141.5438898	146.5397859	62.75663172	63.57773314	0.571743392	0.574665827
27	rown Patch Images\Plot026.jpg	307200	197129	0.641695964	138.2547266	142.6637278	62.68143196	63.30748286	0.560635118	0.559465599
28	rown Patch Images\Plot027.jpg	307200	196660	0.640169271	131.1339469	137.301378	54.96521408	64.49432969	0.599674709	0.538436777
29	rown Patch Images\Plot028.jpg	307200	207821	0.676500651	132.9605237	136.3625957	58.83414092	62.63289548	0.568546341	0.534755277
30	rown Patch Images\Plot029.jpg	307200	214688	0.698854167	136.5242445	142.1264533	68.04131577	64.53711147	0.521262128	0.55735864
31	rown Patch Images\Plot030.jpg	307200	255252	0.830898438	137.832636	144.2680763	60.33116293	64.60019795	0.581812106	0.565757162
32	rown Patch Images\Plot031.jpg	307200	212396	0.691393229	137.2549624	140.785495	55.50998606	62.48408902	0.605712321	0.55209998
33	rown Patch Images\Plot032.jpg	307200	251102	0.817389323	140.438061	146.5595176	68.64542696	64.7140048	0.531620818	0.574743206
34	rown Patch Images\Plot033.jpg	307200	224119	0.729554036	136.7601364	142.0122301	73.24941214	64.58279103	0.484203494	0.556910706
35	rown Patch Images\Plot034.jpg	307200	257967	0.839736328	138.3567278	145.8918699	68.74788636	65.8605805	0.528775069	0.57212498
36	rown Patch Images\Plot035.jpg	307200	267571	0.870999349	135.3233833	144.9391078	76.6762392	68.45179052	0.470976189	0.568388658
37	rown Patch Images\Plot036.jpg	307200	151257	0.492373047	131.2050418	134.1666435	64.96955513	62.56797086	0.515754785	0.5261437
38	rown Patch Images\Plot037.jpg	307200	153361	0.499222005	133.6376067	136.2346946	61.83765755	62.09450915	0.546094644	0.534253704
39	rown Patch Images\Plot038.jpg	307200	155781	0.507099609	133.8912191	135.816287	58.29513869	61.48996855	0.57077947	0.53261289
40	rown Patch Images\Plot039.jpg	307200	186784	0.608020833	142.9784564	144.8646511	63.3740149	61.38876919	0.562529476	0.568096671

Fig. 2. Spreadsheet containing output following the execution of the "Turfgrass Analysis" macro using the settings as shown in Fig. 1.

default macro setting is to save the output as a Microsoft Excel file. Clicking the "OK" button will begin the image analysis process.

RESULTS AND DISCUSSION

The results from analyzing the batch of 489 brown patch images from executing the "Turf Analysis" macro are shown in Fig. 2. The spreadsheet is automatically saved as "Turf Analysis [DATETIME STAMP]" and in this example, the spreadsheet was saved on 17 Sept. 2004 at 2058 h and 45 s. The spreadsheet was saved in, "C:\Documents and Settings\KARCHER\My Documents\Research\NTEP Tall Fescue\Brown Patch Images," the same folder containing the analyzed images.

Column A contains the file path information of each image analyzed. Column B contains the total pixels of each image analyzed and in this example all of the images contained 307 200 pixels (camera resolution was set to 640 × 480). Column C contains the number of pixels representing green turf as determined from the threshold settings. In this example, the first three images have 232 093, 190 246, and 202 479 green turf pixels, respectively. Column D contains the calculated percent turf cover as the quotient of selected pixels to total pixels. In this example, the first three images have 75.6, 61.9, and 65.9% green turf cover, respectively. Columns E through J contain the average color information from either the entire image or the selected pixels, depending on the macro settings. In this example, only the selected pixels representing green turf were used to determine average color (Fig. 1). From the macro output, average turf color may be described using either the red/green/blue or hue/saturation/brightness color model (Karcher and Richardson, 2003).

The example analysis accomplished with the "Turf Analysis" macro, which evaluated 489 images for percent turf cover and turf color, required less than one minute of manual execution. At an average rate of three minutes per image to manually evaluate percent cover and color in SigmaScan Pro, the "Turf Analysis" macro saved more than 24 h of manual, tedious labor. Although the macro can be executed in less than one minute, the analysis will complete at a rate from <5 s to 1 min. per image, depending on the resolution of the images and the computer processing speed.

Although the "Turf Analysis" macro was developed for the analysis of turf images, its utility may be extended to analyze virtually any plant species. Through collaboration efforts with colleagues from the departments of Horticulture and Crop, Soil, and Environmental Sciences at the University of Arkansas, Fayetteville, the macro has been tested successfully in quantifying the colors of poinsettia (*Euphorbia pulcherrima* Willd.) and petunia (*Petunia* spp. Juss.) flowers, spinach leaves (*Spinacia oleracea* L.) and quantifying soybean [*Glycine max* (L.) Merr.] canopy coverage.

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