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Evaluating Multiple Rating Methods Utilized in Turfgrass Weed Science

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Turfgrass weed scientists commonly use visual ratings (VR) to assign a numerical value to a turfgrass or weed response. These ratings lack quantifiable numerical values and are considered subjective. Alternatives to VR, including line intersect analysis (LIA) and digital image analysis (DIA), have been used to varying extents in turfgrass research. Alternatives can be expensive, labor intensive, and can require extensive calibration and increased time for data acquisition. Minimal research has been conducted evaluating rating methods used in turfgrass weed science. Trials were conducted in 2007 and 2008 to evaluate ratings methods used to quantify large crabgrass populations as influenced by tall fescue mowing height (2.5, 5.1, 7.6, and 10.2 cm). Percent large crabgrass cover was assessed utilizing VR, LIA, and DIA to determine if differences existed among evaluation methods. Pairwise comparisons, Pearson's correlation, and linear regression were performed to compare evaluations. All rating methods were significantly correlated to one another. Differences of large crabgrass cover estimates existed between LIA and DIA data at all mowing heights and between VR and DIA data at the 7.6 and 10.2 cm mowing heights in 2007. Authors believe that shadows produced by the turf canopy at higher ($\geq$ 7.6 cm) mowing heights increased DIA estimates of large crabgrass cover. At trial initiation in 2007, researchers did not capture calibration images because the methodology to eliminate a shadow influence using a standard digital image had not been published. Additional DIA calibration in 2008 corrected for canopy shadows, and no differences were observed in large crabgrass cover between all evaluation methods indicated by nonsignificance pairwise comparisons and estimated regression parameters. These data indicate VR are no different than LIA or DIA in estimating large crabgrass cover as affected by tall fescue mowing height.

Nomenclature: Tenacity (mesotrione); large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; tall fescue, *Lolium arundinaceum* (Schreb.) S. J. Darbyshire.

Key words: Digital image analysis, rating methods, SigmaScan, turfgrass, visual estimations.

Los científicos de malezas en céspedes usan estimaciones visuales (VR) para asignar un valor numérico a las respuestas del césped o de la maleza. Estas estimaciones carecen de valores numéricos cuantificables y son consideradas subjetivas. Las alternativas a VR incluyen el análisis de intersección de líneas y análisis digital de imágenes (DIA), que han sido usados en diferentes niveles en la investigación en céspedes. Las alternativas pueden ser costosas, intensivas en labor, y pueden requerir una calibración extensiva e incrementos en el tiempo de adquisición de datos. La investigación que se ha realizado ha sido mínima para evaluar los métodos de evaluación usados en la ciencia de malezas en céspedes. Se realizaron estudios en 2007 y 2008 para evaluar los métodos de evaluación usados para cuantificar poblaciones de *Digitaria sanguinalis* a su vez que la influencia de la altura de poda en *Lolium arundinaceum*.(2.5, 5.1, 7.6 y 10.2 cm). El porcentaje de cobertura de *D. sanguinalis* fue evaluado utilizando VR, LIA y DIA para determinar la existencia de diferencias entre estos métodos de evaluación. Comparaciones de pares, correlación Pearson, y regresión lineal fueron realizadas para comparar los diferentes métodos. Todos los métodos de evaluación correlacionaron entre ellos en forma significativa. Hubo diferencias en la cobertura de *D. sanguinalis* entre los datos de LIA y DIA en todas las alturas de poda y entre los datos de VR y DIA a alturas de 7.6 y 10.2 cm en 2007. Los autores creen que las sombras producidas por el dosel del césped a alturas de poda altas ($\geq$7.6 cm) incrementó los estimados de DIA de la cobertura de *D. sanguinalis*. Al inicio del estudio en 2007, los investigadores no capturaron imágenes de calibración porque la metodología para eliminar la influencia de las sombras usando una imagen digital estándar no había sido publicada. La calibración adicional de DIA en 2008 corrigió por sombras del dosel, y no se observaron diferencias en la cobertura de *D. sanguinalis* entre los diferentes métodos de evaluación, lo cual fue indicado por la no-significancia de las comparaciones de pares y los parámetros de regresión estimados. Estos datos indican que VR no es diferente de LIA o DIA al estimar el porcentaje de cobertura de *D. sanguinalis* al ser influenciada por la altura de poda de *L. arundinaceum*.

Visual ratings (VR) are commonly used in herbicide efficacy trials, including turfgrass weed control research. Due to quickness and ease, VR minimize the time required to assess trials. Visual ratings are conducted by trained evaluators in controlled field, greenhouse, and laboratory experiments and are commonly utilized in assessing turfgrass research trials (Horst et al. 1984). The evaluator visually estimates the response of an individual plot and assigns it a numerical value relative to the nontreated or control in each replicate. Evaluator experience can slightly influence the assessment of plant responses (Horst et al. 1984), but a competent individual with very little training can adequately estimate weed control and cover. Visual ratings are not based on a quantified numerical value and are considered to be subjective ratings (Richardson et al. 2001; Skogley and Sawyer 1992). However, subjective or qualitative data acquisition allows for frequent assessments throughout the growing season (Morris 2002), requires less time compared to line intersect analysis

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(LIA), permits large sample size, and requires minimal equipment expenditure (Horst et al. 1984).

The VR method is commonly used to report turfgrass cultivar performance (Horst et al. 1984; Landschoot and Mancino 2000). Horst et al. (1984) conducted a field study in which 10 trained evaluators rated quality and density of multiple Kentucky bluegrass (*Poa pratensis* L.) and tall fescue cultivars. More variation was reported among evaluators than turfgrass cultivars, making comparison among research trials rated by different individuals inconclusive. Visual estimates of turfgrass cover are variable and difficult to reproduce (Richardson et al. 2001). Visual evaluation of turfgrass quality and density are inadequate in most situations although this method has continued to be used since 1934 (Horst et al. 1984; Richardson et al. 2001).

Another method, LIA, is an alternative to VR that measures ground cover on a point-by-point basis (Cook and Stubbendieck 1986; ITT 1996; Oosting 1956). During LIA, a grid is overlaid above a plot or quadrant and total the number of plants of interest at each intersection in the grid is recorded (Richardson et al. 2001). The recorded number is often divided by the total number of intersections in the grid and multiplied by 100 to calculate a percent cover of the desired plant species. The spacing of intersects, size of the grid, and time allocated for counting determine data precision. Subsequently, the amount of time and labor required for data collection can limit the scope of the research, because LIA is labor intensive (Booth et al. 2005; Richardson et al. 2001).

Digital image analysis is a relatively new evaluation technique that analyzes pixels from digital photographs of research plots using computer software. Digital image analysis has been successfully used to study color differences in corn (*Zea mays* L.) (Ewing and Horton 1999) and soybean [*Glycine max* (L.) Merr.] along with crop canopy coverage (Purcell 2000). This approach has also been developed to determine fractional cover of senescence and green vegetation in rangeland (Laliberte et al. 2007). Digital image analysis has been utilized in turfgrass to assess cover after bermudagrass [*Cynodon dactylon* (L.) Pers.] was seeded during the dormant season and also to determine the recovery of bermudagrass and zoysiagrass varieties [*Zoysia japonica* Steud., *Z. matrella* (L.) Merr, and *Z. tenuifolia* Willd. ex Thiele] from divot or cold injury (Karcher et al. 2005a,b; Patton and Reicher 2007; Shaver et al. 2006). Further, Karcher and Richardson (2003) quantified zoysiagrass and creeping bentgrass (*Agrostis palustris* Huds.) color using DIA. More recently, DIA has been used to assess turfgrass cover after simulated traffic (Brosnan et al. 2010; Goddard et al. 2008; Thoms et al. 2010; Vanini et al. 2007).

Software programs have been developed to conduct DIA on batches of digital images (Booth et al. 2005; Karcher and Richardson 2005). The "VegMeasure" software program, developed at Oregon State University (Johnson et al. 2003; Louhaichi et al. 2001), was used by Booth et al. (2005) to compare methods of measuring ground cover. Booth et al. (2005) reported there was no difference between digital imaging software (VegMeasure) and a digital grid overlay (similar to LIA) when estimating vegetative cover. Other computer programs have used wavelengths to quantify color images of corn (Ewing and Horton 1999). Purcell (2000) and Richardson et al. (2001) used a commercially available software program, SigmaScan (v. 5.0, SPSS, Inc., Chicago IL 60611) to determine the portion of ground area covered by soybean, bermudagrass, and zoysiagrass. Butler et al. (2004) reported that SigmaScan was more effective for assessing spring dead spot (*Ophiosphaerella narmari, O. korrae*, and *O. herpotricha*) incidence in bermudagrass compared to VR. Richardson et al. (2001) determined DIA was effective for measuring turfgrass cover, and reported that DIA and LIA are usually more precise than either LIA or ratings determined visually; however, the researchers mentioned that the time and cost of this type data acquisition often limits use.

During DIA, software programs must be configured to select for what constitutes a green-pixel in each image. The color threshold feature allows the user to search a digital image for a specific hue, saturation, and brightness value in a digital image (Richardson et al. 2001). The threshold settings are effective when only one crop or plant species is being analyzed. When weed responses in turfgrass are quantified, many leaf textures and colors are present in the digital image. All plant material in the digital image would be considered within the threshold for green color. Multiple values and thresholds would be needed to select for individual plant species within a single digital image; thus, batch analyses of digital images that have been successful in reducing evaluation time for large scale turfgrass research projects would not be possible.

Despite the fact that multiple researchers have illustrated the usefulness of DIA for quantifying differences in turfgrass color and cover (Brosnan et al. 2010; Butler et al. 2004; Goddard et al. 2008; Karcher et al. 2005a,b; Patton and Reicher 2007; Richardson et al. 2001; Thoms et al. 2010; Vanini et al. 2007), data describing the use of DIA for quantifying weed responses in turf are limited. Therefore, research was conducted to determine if differences existed among DIA, LIA, and VR for estimating large crabgrass populations as affected by tall fescue mowing height.

Materials and Methods

Field experiments were initiated in Raleigh, NC (RAL) at Lake Wheeler Field Labs (35.74N, –78.88W) and Jackson Springs, NC (JAC) at Sandhills Research Station (35.19N, –79.67W) on March 6, 2007 and March 3, 2008. One experiment was conducted at both locations in 2007 and 2008. Soil was a Wakulla sand (siliceous, thermic psammentic hapludult) in JAC with 0.86% humic matter and pH 5.5. Soil in RAL was an Appling fine sandy loam (fine, kaolinitic, thermic typic kanhapludult) with 1.19% humic matter and pH 5.8.

Areas were mown at 5.1 cm to remove debris prior to seeding large crabgrass. Large crabgrass (Lorenz's Ok Seeds, 511 W Oklahoma, Okeene, OK 73763) was slit and broadcast-seeded at 180 kg ha^{-1}. A slit-seeder (Dethatcher/seeder on 7.6-cm centers, 142 cm wide, Toro Seeder 93, Bloomington, MN 55420) attached to a tractor (John Deere 4700 Tractor, Moline, IL 61265) was used to slit-seed in at least four directions to apply approximately 90 kg ha^{-1} large

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crabgrass seed. A broadcast spreader was then used in two directions to apply the remaining (90 kg ha^{-1}) large crabgrass seed to ensure even seed distribution. All areas were then hand rolled to increase seed-to-soil contact. Seeding was conducted on March 6, 2007 and March 3, 2008. After seeding, each plot location was irrigated with 0.25 cm of water two times daily to ensure ample moisture for germination until emergence occurred ($\sim$ 7 d). Thereafter, all research plots were irrigated as needed to maintain adequate soil moisture.

Treatments (2.5, 5.1, 7.6, and 10.2 cm mowing heights) were initiated when soil temperatures reached a 24-h mean soil temperature of 12.8 C at a 1 cm depth: March 14, 2007 and March 18, 2008 at both locations. Soil temperatures were monitored daily within North Carolina's digital weather and climate database (CRONOS). Treatments were replicated four times at both locations each year. Plots were 2.1 by 1.2 m and treatments were arranged in a randomized complete block design. Mowing treatments were performed every 3 to 4 d with a rotary mower (53.3 cm cutting width, Honda HRC 216, Alpharetta, GA 30005) with clippings returned. Plots in RAL and JAC received granular fertilized (34-0-0, derived from sulfate of ammonia and urea, Harrell's Fertilizer, Inc., Quarters Lane, Charlotte, NC, 28227) monthly at rates of 24 kg nitrogen (N) ha^{-1} and 38 kg N ha^{-1}, respectively, to provide 96 kg N ha^{-1} and 152 kg N ha^{-1}, respectively, for the duration of the trial. Plots at both locations received 0.3 cm of irrigation water immediately following all fertilizer applications.

To provide contrast between large crabgrass and tall fescue, mesotrione (Mesotrione, Tenacity, Syngenta Crop Protection, Greensboro, NC 27409) was applied to mature large crabgrass ($\geq$ 5 tiller) present in the plot area at 0.24 kg ai ha^{-1} with a CO_2-pressurized, hand-held spray boom equipped with four VS8003XR (Teejet Spraying Systems Co., North Ave., Wheaton, IL 60189) flat fan nozzles on a 38-cm spacing calibrated to deliver 304 L ha^{-1}. Mesotrione was applied on September 24, 2007 and September 5, 2008. After mesotrione application, young leaves of large crabgrass were bleached and eventually became necrotic. Mature crabgrass leaves became necrotic. A color contrast is produced due to the susceptibility of large crabgrass and tolerance of tall fescue to mesotrione (Askew and Beam 2002).

Visual ratings, LIA, and DIA were used to assess large crabgrass cover on October 10, 2007 and September 18, 2008. Visual ratings utilized a 0 (no large crabgrass) to 100% (complete large crabgrass cover) scale. For LIA, a 2.1 by 1.2 m grid (5.1 cm spacing) was placed on each plot. The presence or absence of large crabgrass at each intersection was recorded and converted into percent cover using Equation 1:

$$(a/b) \times 100 = c \tag{1}$$

where a is the number of intersects where large crabgrass was present, b is the total number of intersections in the grid (943), and c is percent large crabgrass cover. For DIA, digital images were obtained using a digital camera (Nikon D80, Nikon Inc., Chiyoda-ku, Tokyo, 100-8331, Japan) mounted on a tripod stand (Manfrotto 190XPROB, Ramsey, NJ 07446). Digital image collection was conducted similar to Richardson et al. (2001). The tripod stand consisted of a 90-degree, 24-cm horizontal arm, 122 cm high, which allowed for an image to be captured from directly above the plot; a wired remote was used to operate the camera shutter. Images were saved in the JPEG (joint photographic experts group, .jpg) format and were 560 by 400 pixels with a 64,000 color depth (16-bit). Camera settings included focal length of 32 mm, aperture of F7.1, and a shutter speed of 1/200 s, with white balance set to a natural light source. Digital images were collected between 11:00 A.M. and 2:00 P.M. with 0% cloud cover. All evaluations were conducted by a single individual to minimize evaluator variation.

Digital images were analyzed with SigmaScan Pro (SigmaScan Pro® for Windows®, v 5.0, SPSS, Inc.) according to Karcher and Richardson (2005). Preliminary research determined that optimal hue and saturation settings to estimate tall fescue coverage were 43 to 100 and 0 to 100, respectively. Equation 2 was used to determine the percent large crabgrass cover from the digital images:

$$100 - z = c \tag{2}$$

where z is the percent tall fescue cover as determined from SigmaScan Pro and c is percent large crabgrass cover. Only large crabgrass and tall fescue were present in research plots, totaling 100% cover.

To eliminate a shadow influence, four standard digital images (SDI) were captured on tall fescue plots containing 0% large crabgrass cover at each mowing height and analyzed with SigmaScan. Percent large crabgrass was determined using Equation 2 for the SDI at each mowing height. Values reported by SigmaScan as large crabgrass for the averaged SDI (corresponding to each mowing height) were removed from each digital image after treatment images were analyzed. At trial initiation in 2007, researchers did not capture SDI because the methodology to eliminate the shadow influence using a SDI was not published by previous researchers (Richardson et al. 2001). Therefore, DIA methodology was altered for 2008 digital image acquisition as previously stated.

Three analyses were conducted to determine if differences existed between VR, LIA, and DIA rating methods when estimating large crabgrass cover. Mean separation was conducted by PROC GLM in SAS (SAS® for Windows, v 9.3, Statistical Analysis Systems Institute, Research Drive, Cary, NC 27513) and pairwise comparisons within each mowing height were conducted in PROC MIXED. PROC CORR was used to determine if correlations existed between rating methods. Also, linear regression was conducted using PROC REG for regression coefficient analysis. For presentation purposes, means as determined by SAS were graphed in SigmaPlot (SigmaPlot 11.2® for Windows. SPSS, Inc.).

Results and Discussion

Significant treatment ($P < 0.001$), year ($P < 0.001$), and rating method ($P < 0.001$) main effects as well as treatment-by-rating method within-year interactions ($P = 0.001$) prevented pooling data across years; thus, data were presented separately. Differences in years were due in part to a decrease in large crabgrass populations in 2008 compared to 2007.

Table 1. Comparison of digital image analysis, visual ratings, and line intersect analysis for estimating large crabgrass cover at individual mowing heights of tall fescue in 2007.[a,b,c]

	Large crabgrass cover			VR vs. DIA		VR vs. LIA		LIA vs. DIA	
Mowing height	VR	LIA	DIA	*t* value	P value	*t* value	P value	*t* value	P value
cm		%							
2.5	63.8 a	55.1 a	69.4 a	1.13	ns	−1.73	ns	2.86	0.005
5.2	40.0 b	29.1 b	49.5 b	1.81	ns	−2.09	0.038	4.06	0.001
7.6	10.0 c	7.3 c	21.9 c	2.38	0.019	−0.54	ns	2.92	0.006
10.2	0.0 d	0.1 c	12.6 c	2.51	0.013	0.01	ns	2.51	0.013
LSD (0.05)	9.7	12.2	10.9						

[a] Data pooled over two trial locations; Jackson Springs, NC and Raleigh, NC.

[b] Abbreviations: VR, visual ratings; LIA, line intersect analysis; DIA, digital image analysis; ns, nonsignificant.

[c] Means within a column followed by the same letter are not significantly different according to Fisher's LSD, P = 0.05.

Large crabgrass populations naturally diminished by the September rating date in 2008 due to a decreased ambient temperature. Each year, as mowing height increased, large crabgrass cover decreased (Tables 1 and 2). Dernoeden et al. (1993) reported similar results where smooth crabgrass [*Digitaria ischaemum* (Schreb.) Schreb. ex Muhl..] increased with decreasing mowing heights from 8.8 to 3.2 cm.

In 2007, all four mowing treatments varied in large crabgrass cover based on VR, whereas only three statistical groups were detected using DIA and LIA (Table 1). LSD values in 2007 for DIA and LIA were 10.9 % and 12.2%, respectively, and VR resulted in the smallest LSD value of 9.7%. In 2008, all rating methods resulted in three statistical groupings in large crabgrass cover (Table 2). The presence of large crabgrass at the 10.2 cm mowing height did not allow for separation into an additional group. The inability to differentiate among treatments can be a problem in turfgrass trials, especially those with a wide range of treatments over multiple sites (Richardson et al. 2001).

Pairwise comparisons were conducted at each mowing height within year to determine if differences occurred among rating methods. In 2007, LIA and DIA did not similarly estimate large crabgrass incidence at each mowing height (Table 1). DIA resulted in greater large crabgrass cover estimates compared to LIA. The authors believe shadows influenced the SigmaScan analysis, resulting in overestimates of large crabgrass cover. Estimation by LIA was not influenced by shadows due to the evaluator's ability to remove shadow effects during evaluation. When comparing LIA to VR, only the 5.2 cm mowing height differed in estimated large crabgrass cover (t value = –2.09, P value = 0.038). Visual ratings estimated large crabgrass cover to be 10.9% greater than LIA at the 5.2 cm mowing height. Differences in large crabgrass cover were also detected between VR and DIA at the 7.6 and 10.2 cm mowing heights in 2007. Due to increased accuracy of LIA and no observed difference in large crabgrass cover using VR and LIA at the 7.6 and 10.2 cm mowing heights, authors believe that DIA overestimated large crabgrass cover in 2007. Thus, estimates of large crabgrass cover using DIA differed from those determined using LIA or VR. At higher mowing heights, shadows are produced by the turf canopy. SigmaScan Pro detected these shadows as part of the large crabgrass population present in the tall fescue sward, which overestimated large crabgrass populations at higher mowing heights.

At each mowing height in 2008, no differences in large crabgrass cover were detected when comparing VR vs. DIA, VR vs. LIA, and DIA vs. LIA (Table 2). Increased DIA precision and accuracy in 2008 was achieved by eliminating a shadow influence at each mowing height by use of SDI.

All rating methods were significantly correlated to one another ($P < 0.001$) (Table 3). Correlations allowed for linear regression analysis between rating methods. As conducted by Richardson et al. (2001), when two rating methods are regressed against one another, in the same numerical scale, differences in rating methods can be determined. Two rating methods can be considered equivalent when the slope estimate is one, the intercept estimate is

Table 2. Comparison of digital image analysis, visual ratings, and line intersect analysis for estimating large crabgrass cover at individual mowing heights of tall fescue in 2008.[a,b,c]

	Large crabgrass cover			VR vs. DIA		VR vs. LIA		LIA vs. DIA	
Mowing height	VR	LIA	DIA	*t* value	P value	*t* value	P value	*t* value	P value
cm		%							
2.5	55.0 a	48.1 a	47.8 a	−1.43	ns	−1.38	ns	−0.05	ns
5.2	28.8 b	25.7 b	23.9 b	−0.96	ns	−0.60	ns	−0.36	ns
7.6	10.6 c	9.9 c	10.1 c	0.05	ns	−0.15	ns	0.20	ns
10.2	4.4 c	3.7 c	8.9 c	0.92	ns	−0.13	ns	1.05	ns
LSD (0.05)	8.9	13.9	9.7						

[a] Data pooled over two trial locations; Jackson Springs, NC and Raleigh, NC.

[b] Abbreviations: VR, visual ratings; DIA, digital image analysis; LIA, line intersect analysis; ns, nonsignificant.

[c] Means within a column followed by the same letter are not significantly different according to Fisher's LSD, P = 0.05.

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Table 3. Pearson correlation coefficients comparing rating methods to predict large crabgrass cover in tall fescue research plots in Jackson Springs and Raleigh, NC during 2007 and 2008.[a,b]

	2007			2008		
	VR	LIA	DIA	VR	LIA	DIA
VR	1.0			1.0		
LIA	0.93***	1.0		0.98***	1.0	
DIA	0.95***	0.90***	1.0	0.88***	0.88***	1.0

[a] Abbreviations: VR, visual ratings; LIA, line intersect analysis; DIA, digital image analysis.

[b] Correlation coefficients were nonsignificant (ns) or significant at *P ≤ 0.05, **P ≤ 0.01 or ***P ≤ 0.001.

zero, and a high correlation producing a 1 : 1 relationship is detected (Richardson et al. 2001). This technique uses the liner equation (Equation 3):

$$y = mx + b \tag{3}$$

where y is the response (i.e., percent large crabgrass measured using one type of rating method), m is the slope, x is the predictor (i.e., percent large crabgrass measured using another rating method), and b is the intercept (Richardson et al. 2001).

No differences in slope were observed between rating methods in 2007 concluding homogeneous slopes (Table 4 and Figure 1) (Quinn and Keough 2002). However, differences in intercept estimates were observed in 2007.

When comparing DIA data to those generated using VR or LIA, intercept estimates were different than zero (Table 4). When analyzing VR and LIA data, intercept estimates were not different from zero, suggesting that these rating methods were not different from one another. This further supported the suspected calibration error in DIA because differences occurred between DIA and VR or LIA and no differences were observed by VR and LIA when testing H_o: $b = 0$, H_a: $b \neq 0$ and H_o: $m = 1$, H_a: $m \neq 1$. No slope or intercept differences were observed among rating methods in 2008. After DIA calibration in 2008, no differences in large crabgrass cover were detected among the three rating methods at multiple mowing heights. Authors believe that no differences were observed due to the elimination of the shadow influence at each mowing height.

Implications for Application. These data indicate DIA, LIA, and VR are effective tools for estimating large crabgrass cover in tall fescue research plots. Visual ratings and DIA are less time-consuming compared to LIA (Richardson et al. 2001), allowing evaluators more time to rate multiple research plots. Visual ratings required the least time of all evaluated rating methods and can also compensate for nontarget species or plot damage by various factors such as mower scalping or pests.

Digital image analysis can be influenced by external (i.e., nontreatment) effects, within a plot, causing incorrect data to be reported. The inability to remove external effects was exemplified in the current experiment where DIA was not able to differentiate between turfgrass canopy shadows and large crabgrass. Following the digital image analysis procedure outlined by Richardson et al. (2001), a uniform light source (Ikemura 2003) was not utilized, and might have been able to eliminate the shadow effect in the 2007 data. The use of a constant light source could also have eliminated the need for further calibration in 2008. Once initial calibration was conducted, DIA did not require a trained evaluator or the same evaluator for subsequent assessments. Digital image analysis differentiates between plant species according to the chosen hue. Although capturing digital images requires a short amount of time, initial calibration of DIA is time consuming. Also, DIA was costly, because equipment was moved to and from each research site and software (i.e., SigmaScan) had to be purchased for this experiment as open source software, but was not utilized.

For DIA to be an effective methodology in turfgrass weed science research, color differences must be detectable between weed and turfgrass species throughout the trial period. In this trial, mesotrione was used to create a sharp color difference between the turfgrass and weed species that would not be

Table 4. Comparison of estimated regression parameters for each evaluated rating method used to predict large crabgrass populations in tall fescue research plots maintained at various mowing heights in Jackson Springs and Raleigh, NC during 2007 and 2008.[a,b]

	2007						2008					
	Intercept [c]			Slope [d]			Intercept			Slope		
	Est[e]	*t* value	P value	Est	*t* value	P value	Est	*t* value	P value	Est	*t* value	P value
VR vs. DIA	−10.77 (± 2.79)	−3.85	0.001	1.02 (± 0.06)	0.33	ns	−0.52 (± 3.18)	−0.16	ns	1.10 (± 0.11)	0.91	ns
VR vs. LIA	2.39 (± 2.43)	2.05	ns	1.01 (± 0.07)	0.14	ns	0.61 (± 1.17)	0.53	ns	1.10 (± 0.14)	0.71	ns
DIA vs. LIA	−11.36 (± 3.56)	−3.18	0.003	0.89 (± 0.08)	−1.38	ns	−0.73 (± 2.78)	−0.27	ns	0.98 (± 0.09)	−0.22	ns

[a] Linear regression equation: $y = m(x) + b$; m, slope; b, intercept; Figure 1.

[b] Abbreviations: Est; estimate; VR, visual ratings; DIA; digital image analysis; LIA, line intersect analysis; ns, nonsignificant.

[c] Intercept test: H_o; $b = 0$ and H_a; $b \neq 0$.

[d] Slope test: H_o; $m = 1$ and H_a; $m \neq 1$.

[e] Estimate followed by standard error in parenthesis calculated at P = 0.05 significance level.

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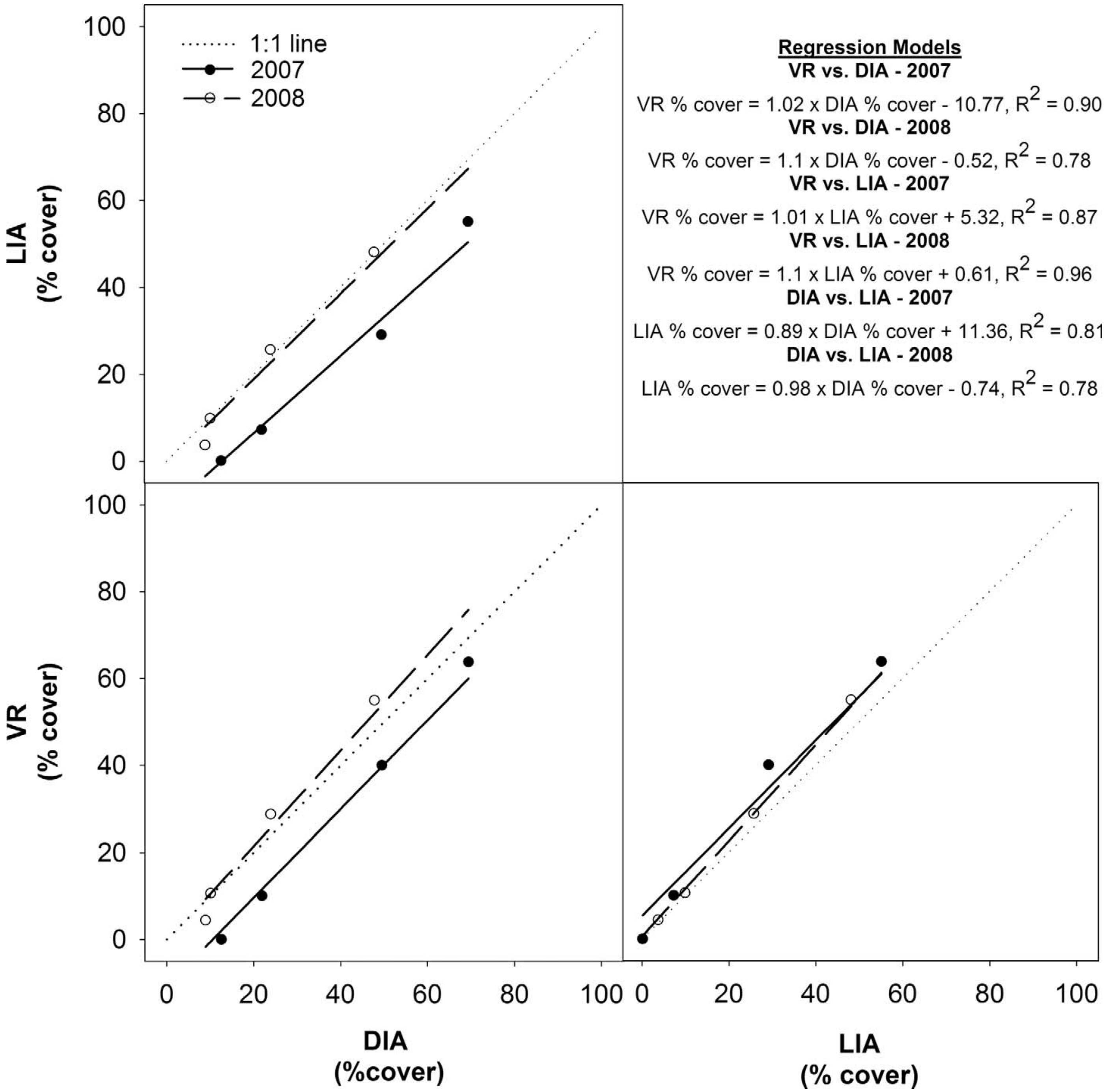

Figure 1. Linear regression analysis of percent large crabgrass cover, manipulated by mowing height, measured using digital image analysis (DIA), line intersect analysis (LIA), or visual ratings (VR) in tall fescue research plots located in Jackson Springs and Raleigh, NC during 2007 and 2008.

present naturally. Mesotrione inhibits carotenoid biosynthesis turning susceptible species (i.e., large crabgrass) white and leaving tolerant species (i.e., tall fescue) unaffected. Although a color difference was obtainable in this research, it might not always be feasible in all research scenarios. Visual ratings and LIA can be conducted multiple times during a trial to collect more meaningful data across a designated time period. Therefore, VR are useful for turf weed science experiments. Our findings indicate that estimates of large crabgrass cover using VR are not different than those generated using the other rating methods evaluated in this study.

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