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Image Analysis Compared with Other Methods for Measuring Ground Cover

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Ground cover is a key indicator of rangeland health but conventional methods for measuring ground cover are labor intensive. Analysis of digital images has the potential to reduce ground-cover-measurement labor requirements. We compared cover measurements by image analyses of digital images (sensor resolution = 0.97 mm/pixel ground sample distance) with measurements derived from a laser point frame, and from two transect methods. We found there was low agreement in plot-to-plot comparisons but results were usually not different when averaged over a large number of plots or transects. We conclude that image analysis of large numbers of samples (images) produce mean values not different from conventional field methods, and, that image analysis is a superior choice for detecting relative change, since it facilitates greater data collection, reduces human bias by limiting human judgments, and provides a permanent record in images that can be retained for future scrutiny.

Keywords bare ground, digital image, green vegetation cover, line intercept, pace transect, point frame, VegMeasure, remote sensing

Ground cover is a key indicator of rangeland "health" (USDI-BLM, 1997). Conventional methods for measuring ground cover include point and line intercept techniques (Oosting, 1956; Cook & Stubbendieck, 1986; ITT, 1996). Although the camera was employed early as a means for capturing the nadir perspective of plant communities (Cooper, 1924; Rowland & Hector, 1934), and while discussions of photographic methods for quantifying plant cover have remained in the literature (Claveran, 1966; Wells, 1971; Tueller et al., 1972; Owens et al., 1985; Bennett et al., 2000), there is little evidence of confidence in photographs for objective measurements comparable to point and line-intercept methods. Mueller-Dombois &

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Ellenberg (1974, page 83) observed "photographs often suffer from unclear background, creating difficulty in subsequent interpretation of plant outlines on prints." This is no longer true. Modern, high-quality digital cameras capture images that clearly resolve vegetation and background. Here we compared the labor requirements and data from standard techniques with that of modern digital image acquisition and analysis.

Methods

Image Acquisition

We acquired our imagery using an Olympus E20, 5-megapixel, digital single lens reflex camera mounted on an aluminum camera frame with a 1-m^2 base that positioned the camera for nadir images 2 m above ground level (Booth, et al., 2004a). Images were acquired by a single person and were saved as uncompressed color Tagged Image File Format (TIFF) files (red, green, blue bands; sensor resolution = 0.97 mm/pixel ground sample distance, Comer et al., 1998).

Digital Grid Overlay

We measured cover manually from images using a semitransparent digital grid overlay (Corel, 1997) of 100 points on each image in a manner similar to the methods advocated by Claveran (1966, citing Avery, 1962) and Wells (1971). We classified "hits" as green cover (grass, forb, shrub), litter, bare ground and rock, from which bare ground and green cover values were summed.

Image Analysis Software

We used "VegMeasure," a software program developed at Oregon State University for measuring plant cover on rangeland (Louhaichi et al., 2001; Johnson et al., 2003), to make automated cover measurements. VegMeasure is designed to quantify green-leaf area in large batches of digital images and is a program we have found to be more easily used for measuring cover in rangeland imagery than other software packages. The Green Leaf algorithm was used for measuring green cover, and the Blue Band algorithm was used for measuring bare ground.

The threshold for VegMeasure color recognition is adjustable. Our method for calibrating the threshold (Booth et al., 2004b) employed the digital grid overlay method, as described above. A 10% subset of the image set was used to calibrate the VegMeasure threshold by adjusting the threshold for each subset image until the software recognized the same amount of bare ground/green cover as the digital grid overlay measurement. Thresholds gathered in this way were averaged for the 10% of images in a set, and the average threshold used to batch process the entire image set.

Point Frame

The VegMeasure data were compared to point data collected using a laser point frame (VanAmburg, 2003) custom built by the Colorado State University Agriculture Engineering and Research Center, Fort Collins, Colorado. The laser point frame is supported 33 cm above ground level over a 1-m^2 quadrat and uses 10 lasers equally spaced 10 cm apart in a nadir orientation. The lasers have a 650 nm wavelength, with a maximum average radiant power of 3.5 mW, an operating voltage of 3–5 VDC, and a laser dot footprint of 0.79 mm^2. The dots were read as sampling points and we used 100 points per quadrat. Welch's unequal variance correction was applied to comparisons that failed an equal variance t-test.

Green Cover—Central Plains Experimental Range

The Central Plains Experimental Range is located 12 km north of Nunn, Colorado, in the northern portion of the shortgrass prairie (40°49′ N, 107°47′ W, average elevation = 1646 m). The average annual precipitation is 320 mm, of which 70% occurs during the growing season from April through August (Hazlett, 1998). Soil is fine sandy loam, and the vegetation is dominated by blue grama grass [*Bouteloua gracilis* (H.B.K.) Lag.], threadleaf sedge [*Carex filifolia* (Nuttall.)], fringed sagewort [*Artemisia frigida* (Willd.) Klein], and plains prickly pear cactus [*Opuntia polyacantha* (Haw.)] (Hazlett, 1998).

A measure of green-leaf cover from stratified-random samples was desired. Images were acquired in May, June, and September, 2002, of 25, 1-m^2 plots in each of three pastures treated by heavy, moderate, and no grazing. Concurrently, a two-member Agricultural Research Service (ARS) crew collected 100-point laser point frame data for each plot. VegMeasure analysis with a calibrated threshold was carried out with the images, and the resulting data was compared to the green-cover laser point frame measurements using t-tests.

Green Cover and Bare Ground—Beaver Meadows

The Upper Beaver Meadows site is located within Rocky Mountain National Park (Rocky Mountain NP), approximately 7 km west of Estes Park, Colorado (40°22′ N, 105°36′ W, elevation = 2573 m). Annual precipitation averages 360 mm, with approximately 50% of precipitation falling as rain during the period between May and August. Soil is well drained sandy/gravelly loam of granitic origin. Vegetation is dominated by antelope bitterbrush [*Purshia tridentata* (Pursh) DC.], mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. vaseyana (Rydb.) Beetle], ponderosa pine [*Pinus ponderosa* (P&C) Lawson], mountain muhly [*Muhlenbergia montana* (Nutt.) A.S. Hitchc.], Parry's oatgrass [*Danthonia parryi* Scribn.], and needle and thread grass [*Hesperostipa comata* Trin. & Rupr.].

Images were collected at six preexisting vegetation monitoring plots located within a single brush-grassland ecotype site at Beaver Meadows. The images were collected concurrent with the reading of the plot transects by park staff using methods adopted by Rocky Mountain NP. Each plot consisted of two 50-m transects running parallel 25 m apart. Along each transect, a point was classified to functional group every 30 cm, for a total of 166 points/transect, by a two-member Rocky Mountain NP crew. Images were collected every 5 meters along each transect for a total of 10 photos/transect, 20 photos/plot, 120 photos total. Green cover and bare ground were measured from the images using the same method as described for the Central Plains Experimental Range: a digital grid overlay of 100 points/image and calibrated VegMeasure analysis. Data generated by image analysis was compared to the field data collected by Rocky Mountain NP staff using one-way ANOVA.

Bare Ground—South Fork Powder River

The South Fork Powder River Watershed, located approximately 65 km northwest of Casper, Wyoming (43° 15′ N, 107° 1′ W) encompasses 70,800 ha, ranging in elevation from 1,600 to 2,600 m. Average annual precipitation is 288 mm. Loamy, sandy, clayey and saline soils are present. Half of the area in the watershed is covered with Wyoming big sagebrush [*Artemesia tridentata* Nutt. ssp. wyomingensis Beetle & Young]/grassland vegetation type. Major species comprising this type are Wyoming big sagebrush, blue bunch wheat grass [*Pseudoroegneria spicata* (Pursh) A. Löve], western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], Sandberg bluegrass [*Poa secunda* J. Presl] and Indian ricegrass [*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth]. Other vegetation types include greasewood [*Sarcobatus vermiculatus* (Hook.) Torr.] and desert saltbush [*Atriplex gardneri* (Moq.) D. Dietr.].

Fifteen 1-m^2 plots were photographed inside Bureau of Land Management (BLM) grazing allotment 10036. Digital grid overlay and calibrated VegMeasure analysis were used to measure bare ground from the images. At the same 15-plot locations a two-member BLM crew collected cover data using the frequency frame (also called a "range fork") with pace transects (ITT, 1996). The BLM method consists of two transects, each with 25 plots three paces apart, with each plot having at least five points classified for basal cover, yielding a total of at least 250 points/transect. VegMeasure bare-ground measurements were compared with frequency frame bare ground measurements using one-way ANOVA and Tukey's mean separation.

Bare Ground—Muddy Creek

Nineteen plots were photographed in May 2002 in a saltbush (*Atriplex*)/grass community in the Red Wash plain (41° 18′ N, 107° 50′ W) within a public grazing allotment of the Muddy Creek watershed approximately 70 km southwest of Rawlins, Wyoming. The area averages 2,033 m elevation and receives 256 mm annual precipitation (Reiners & Thurston, 1996). Ground cover for all plots was measured using the laser point frame technique in the field by a two-member ARS crew, and by digital grid overlay and calibrated VegMeasure techniques from the imagery. Laser point frame, digital grid overlay and VegMeasure measurements were compared using a one-way ANOVA.

In summary, bare ground measurement was tested at three sites, and green cover at two sites. Comparisons to conventional methods were made at Beaver Meadows (point intercept transect method), South Fork Powder River Watershed (frequency frame) and at the Central Plains Experimental Range and Muddy Creek Watershed (ARS laser point frame method). Digital grid overlay and calibrated VegMeasure techniques were used at all sites.

Results

Central Plains Experimental Range

Each set of 25 images took 30 to 40 minutes to calibrate the threshold (digital grid overlay) and less than 1 minute to obtain green-cover measurements using VegMeasure with the calibrated threshold. VegMeasure-derived cover measurements were no different than measurements derived by using the 100-point laser point frame in eight of twelve comparisons ($\alpha = 0.05$) (Table 1). Of the four comparisons that showed a difference, the VegMeasure value was higher once, and lower three times. The highest deviation from the laser point frame data was −8.4% cover.

VegMeasure green cover data for each plot, regressed with laser point frame-derived green cover data, resulted in an R^2 of 0.184 (n = 300), but means were not different at P = 0.10 in eight of 12 data sets. The same data regressed with the 100 point digital grid overlay resulted in an R^2 value of 0.599 (n = 300), again with means that were not different in eight of 12 data sets at P = 0.10.

Rocky Mountain National Park

Bare ground measured from point intercept transects was not different from the VegMeasure-derived values whereas green cover was higher ($P \leq 0.001$) (Figure 1A, B). Bare ground, as measured by the point intercept transects, averaged 4.6% with a range of 1.2 to 13.9% (n = 12), compared to the VegMeasure measurement average of 7.9%, with a range of 0.21 to 30.9% (n = 120). Green cover, as measured by the point intercept transects, averaged 67.5% with a range of 52.4 to 86.1% (n = 12), compared to the VegMeasure average of 36.3% with a range of 18.0 to 62.2% (n = 120).

Table 1. Measurements of green cover (%) from a traditional 100-point ground truth method (n = 9) and image analysis of ground plot images (n = 25) sorted by sample date and pasture (±SD) and P-values generated from t-tests. Where measurements differ significantly (P<0.10, shown in bold), deviation from the ground truth method data is also noted. Data were collected in 2002, a drought year in which little green-up occurred until August.

Month	Pasture	100-point laser frame	VegMeasure[1]	*P*-value[2]	% Diff
	1	2.96 ± 2.00	7.9 ± 4.1 (0.063)	**<0.0001**	+4.61
May	2	5.18 ± 5.03	8.3 ± 4.6 (0.069)	0.1384	
	3	2.59 ± 2.78	9.8 ± 3.5 (0.046)	0.4681	
	1	12.21 ± 5.52	5.7 ± 1.5 (0.050)	**<0.0001**	−6.49
June	2	12.95 ± 3.09	4.7 ± 1.7 (0.053)	**0.0138**	−8.28
	3	12.95 ± 7.71	4.5 ± 2.2 (0.037)	**<0.0001**	−8.42
	1	14.06 ± 7.59	18.5 ± 3.5 (0.035)	0.1233	
Sept.	2	12.21 ± 10.53	16.6 ± 2.8 (0.032)	0.2566	
	3	16.23 ± 13.84	20.1 ± 5.4 (0.033)	0.4410	
	1	5.81 ± 5.9	4.6 ± 0.8 (0.081)	0.5536	
Oct.	2	1.85 ± 3.38	3.4 ± 0.8 (0.085)	0.2020	
	3	2.96 ± 2.6	4.2 ± 1.1 (0.037)	0.1894	

[1]Means derived from batch processing 25 digital images in VegMeasure using a green-band threshold. The threshold was calibrated by manually classifying 100 points/image on a 10% subset of the full image set, then adjusting the VegMeasure threshold until it measured the same amount of green cover as was measured with the digital grid overlay. The calibration threshold used is noted in parentheses.

[2]Where comparisons failed to pass an equal variance test, Welch's unequal variance correction was applied to the T-test. Such comparisons are not individually marked to avoid confusion with denoting significance of *P*-values.

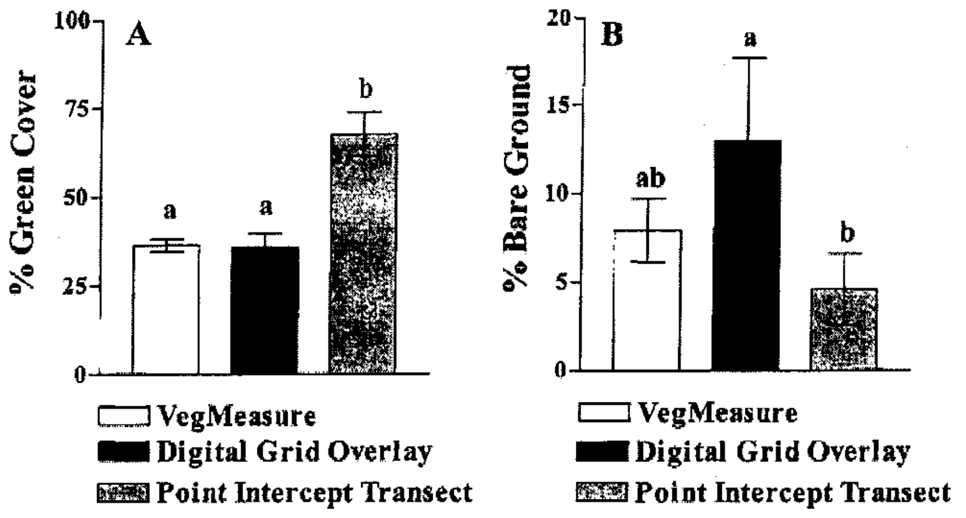

Figure 1. Green cover (A) and bare ground (B) (±95% CI) measured by VegMeasure, digital grid overlay, and permanent point-intercept transects at Beaver Meadows (n = 12). Means with different letters (a,b) are significantly different at $\alpha = 0.001$. Each transect replicate used 166 points. Each VegMeasure and digital grid overlay replicate used 10 images. Each VegMeasure image used 4 million data points and each digital grid overlay image used 100 data points. VegMeasure image analysis resulted in a *lower* green cover and an equal bare ground measurement relative to reading the permanent transects.

South Fork Powder River

The bare ground measurement obtained using the frequency frame was lower by 13% than the measurement obtained using VegMeasure (P = 0.038, Figure 2). Bare ground averaged 21.2% from the frame and ranged from 11.4 to 63.5% (n = 15) compared to the VegMeasure average of 34.5% with a range of 18.8 to 46.6% (n = 15).

Muddy Creek

Bare ground measurements derived from use of the laser point frame digital grid overlay and VegMeasure were not different (P= 0.314, n = 19) (Figure 3). Bare ground averaged 70.1% and ranged from 50 to 97% for laser point frame, (n = 19) 67.6% with range of 59 to 97% for digital grid overlay (n = 19), and 65.3% with range of 24.2 to 89.3% for VegMeasure (n = 19).

Discussion and Conclusions

Standard methods for collecting cover data are labor intensive—a fact that limits the acquisition of statistically-adequate data sets across allotment pastures and similar management units. In all cases of our study, image acquisition and analysis required less labor than conventional methods, primarily because image analysis required only one worker, whereas other field methods required two (Table 2).

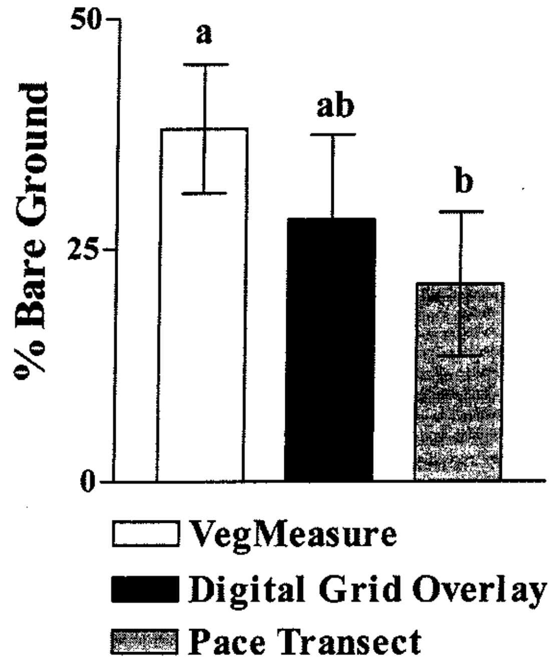

Figure 2. Bare ground (±95% CI) measured by VegMeasure, digital grid overlay and pace transects in the South Fork Powder River Basin. Means with different letters (a,b) are significantly different ($P = 0.038$, $n = 15$). Each transect replicate used a minimum of 250 points. Each VegMeasure replicate used 4 million data points and each digital grid overlay replicate used 100 data points. VegMeasure image analysis resulted in a *higher* bare ground measurement than measured by the pace transect method.

VegMeasure produced means in agreement with standard methods when compared over multiple plots (over 2/3 of compared data sets showed no significant difference at $\alpha = 0.01$), but do not agree when compared by individual plot for some communities. This implies that errors for image analysis are random and therefore compensating. Large numbers of replicated plots should be used in any field study; however, researchers should continue to look at plot-to-plot differences as an opportunity to improve image-analysis measurement accuracy.

We found that VegMeasure measurements indicated more bare ground than was measured using the frequency frame and was about equal with Rocky Mountain NP's point intercept transects and the laser point frame. Why the differences with frequency frame data? For images used in this study and for the laser point frame, contact points (pixel resolution in the case of the images) was about 1 mm, whereas points of the frequency frame used were larger than 1 mm. That difference might account for differences in data outcomes (Cook & Stubbendieck, 1986, page 59).

A similar situation is evident when assessing green cover. VegMeasure measured green cover lower than the Rocky Mountain NP point intercept transects, and lower than the 100-point laser point frame in three of 12 comparisons at the Central Plains Experimental Range. However, it measured green cover the same as the 100-point laser point frame in eight of 12 comparisons at the Central Plains Experimental Range, and measured it higher in one of 12 comparisons. Differences between

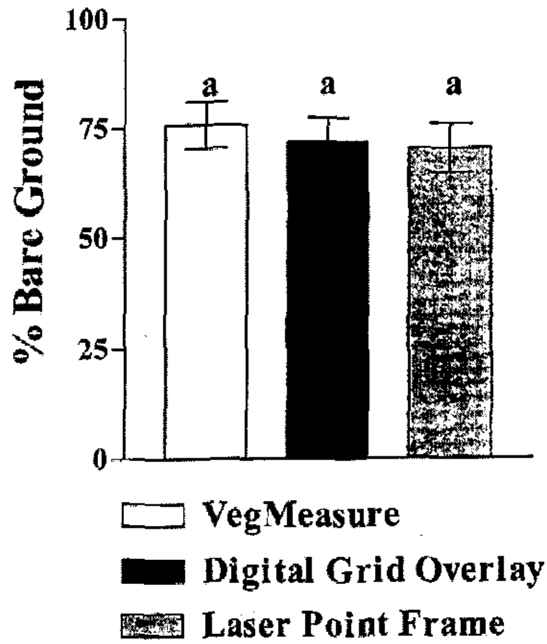

Figure 3. Bare ground (±95% CI) measured by VegMeasure, digital grid overlay and laser point frame in the Muddy Creek watershed. Means were not significantly different. Each laser point frame replicate used 100 data points. Each VegMeasure replicate used 4 million data points and each digital grid overlay replicate used 100 data points. Image analysis resulted in a bare ground measurement no different than the laser point frame method ($P = 0.314$, $n = 19$).

Table 2. Time (man-hours) required to complete vegetation cover analysis using tested methods. Travel time to and from plots is not included since it is equal for each method at each study site[1]

Site (n)	n	Image analysis	Digital grid	LPF[3]	RMNP[4]	BLM[5]
CPER[6]	27	3	5	9		
Beaver Meadows	6[2]	7	22		12	
Powder River	15	2	3			17.5
Muddy Creek	18	2	3.5	6		

[1]We used 10 minutes/plot for Laser Point Frame × 2 workers or Digital Grid × 1 worker, 35 minutes/transect × 2 workers for BLM Frequency Frame/Pace Transects, 60 minutes/plot × 2 workers for Rocky Mountain NP point intercept transects and 1 min/plot × 1 worker for image acquisition. Time for image analysis is neglected since it is 1–2 minutes per batch.
[2]Sample size = 6 treatment plots with 2 transects each. Each transect was photographed 10 times for a total of 120 images.
[3]LPF = Laser Point Frame.
[4]RMNP = Rocky Mountain National Park Point Intercept Transects.
[5]BLM = Bureau of Land Management Frequency Frame/Pace Transects.
[6]CPER = Central Plains Experimental Range.

VegMeasure measurements and laser point frame measurements were greatest for June Central Plains Experimental Range data (Table 1). We believe drought conditions resulting in limited, scattered green growth, made it difficult to accurately classify green cover from spectral reflectance. Overall, the data indicate that VegMeasure measures green cover lower than conventional methods, but not every time, and not by much. VegMeasure measurements had a standard error less than half the standard error of other methods in 13 of 17 comparisons (Table 1, Figures 1, 2, 3), implying greater precision in that measurement method. A consideration of VegMeasure with all other methods is that VegMeasure analysis relies on millions more data points, and is less influenced by human bias. On the other hand, VegMeasure (like all spectral-reflectance programs) cannot distinguish among different cover characteristics that have similar spectral reflectance. Examples include similarly colored litter, rock and soil, or any set of differing cover characteristics that may be masked by shadow.

We conclude that ground-cover measurement by image analysis has comparability with conventional methods and that it is a superior choice for detecting relative change because it: (1) facilitates extensive data collection by reducing the labor requirement for monitoring, (2) reduces human bias by limiting the influence of human judgment, (3) is more precise, and (4) provides a permanent record of images that can be retained for future scrutiny. With increasing use of images and their analysis, and as researchers and land managers become comfortable with computer measurements, human resources may be devoted to other, more complicated tasks.

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