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METHOD TO ESTIMATE VEGETATIVE COVER ON ARMY TRAINING LANDS

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METHOD TO ESTIMATE VEGETATIVE COVER ON ARMY TRAINING LANDS

1. Purpose. This Public Works Technical Bulletin (PWTB) describes a method for estimating percent ground cover and environmental damage caused by off-road vehicle traffic at U.S. Army installations.

2. Applicability. This PWTB applies to all continental U.S. (CONUS) and outside CONUS (OCONUS) Army training and testing facilities.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 21 February 1997.

b. See additional references in Appendix E.

4. Discussion.

a. The U.S. Army manages over 12 million acres of land in order to support mission readiness through military training and testing activities (Houston et al. 2001). The training lands at most Army installations are in use constantly for ground training and tracked vehicle maneuvers that result in damage to ecosystem structure and function (Dale et al. 2002). The loss of Army training lands to severe soil erosion due to mission impacts has resulted in increasing investments in land monitoring and rehabilitation (Vachta and Hutchinson 1990; Althoff et al. 2004).

b. Models that predict the effects of training on land are based on a narrow timeframe and often do not calculate cumulative effects over long time periods. Temporal variations due to military training are extreme and difficult to predict. The cumulative effects of damages caused by military training can affect ecosystem health and the potential for successful rehabilitation. Removal of vegetation can increase the amplitude of soil moisture oscillations, for example, which will impact revegetation and recovery over time (Milton 1995). Ecological sustainability is related to a broad time frame (Smyth and Dumanski 1995), so predictions based only on current conditions are unreliable. In addition, field tests on Army installations have shown collection of field data to be labor- and time-intensive, and, often, excessive amounts of data are collected for sites that require only minimal recovery effort (Vachta and Hutchinson 1990).

c. Assessing the sustainability of training lands is further complicated because of heavy land use by vehicles that results in excessive loss of vegetative cover (Foster et al. 2004). The evaluation of ground cover is a necessary component of land management models, since it is a primary indicator of a stable and sustainable soil base that is needed for protection from soil erosion (O'Brien et al. 2003). Visual cover estimates are often used as a rapid method for erosion control projects. Percent plant cover can also be determined using the point-intercept method (Stocking 1994; Vachta and Riggins 1990) with frequent sampling during defined times of the growing season (Herrick and Whitford 1995). These methods to obtain estimates of vegetative cover are labor-intensive, which may decrease the ability of land managers to take repeated samples during the same year (Althoff et al. 2004).

d. A simpler method would decrease time and labor requirements of data collection to estimate vegetative cover on Army training and testing lands. Analysis of digital images can be a useful technique (Fransen et al. 1998; Althoff et al. 2004) because the images can be randomly and quickly acquired along transects or grids. Digital imagery processing software can be used to determine the relative amount of pixels within the image that represent percent cover. A database of images can be kept to provide a temporal record of vegetative cover of a sampling site.

e. This report summarizes efforts to develop an effective method to estimate ground cover on Army installations using digital imagery. A cost-effective method to estimate vegetative cover for use in various erosion potential models would reduce costs of erosion control projects on U.S. Army training and testing lands. The method results in quantitative data that are inexpensive to obtain, repeatable, and useful for documenting changes in vegetative cover over time.

f. Appendix A contains background information.

g. Appendix B contains project details and data collection information.

h. Appendix C contains study results.

i. Appendix D contains summary information.

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APPENDIX A

INTRODUCTION

The U.S. Army manages over 12 million acres of land (Houston et al. 2001), most of which is in constant use by military trainers to meet mission requirements (Fang et al. 2002; Milchunas et al. 2000). These large expanses of land are used to conduct deployment, tactical positioning, camouflage, and offensive and defensive maneuver operations. Environmental impacts on ecosystems from military training are similar to consequences from military actions during wartime (Austin and Bruch 2000; Whitecotten et al. 2000; Dudley et al. 2002). Plant populations may be greatly reduced or altered due to vehicle operations that can result in the clearing of vegetation and severe soil compaction. Soil conditions are changed due to the removal of vegetation, the erosion of topsoil and the mixing and compaction of soil horizons. These changes can result in erosion, water pollution, and loss of habitat for species (Jansen 1997). Degradation of soils in military training areas can result in significant reductions in plant diversity (Dale et al. 2002) with negative impacts to ecosystems.

Installation land managers must inventory and monitor vegetative cover in order to estimate erosion potential and ecological health of training lands. The Universal Soil Loss Equation (USLE) provides a rough estimate of erosion (Tiwari et al. 2000) and is used by land managers to determine erosion potential of selected areas of concern. The USLE includes a cover management factor, C, or the ratio of soil loss from an area with specified vegetative cover. The Army Training and Testing Area Carrying Capacity (ATTACC) program is a software model used to determine land rehabilitation and maintenance costs associated with land-based military training. ATTACC is part of the Army's Integrated Training Area Management (ITAM) Program, mandated for all Department of Defense (DOD) installations. The ATTACC model uses the C factor from the USLE to calculate current land condition as a means to estimate the erosion status of soils (U.S. Army Environmental Center 1999). The Army currently uses vegetative cover surveys to monitor land condition; however, methodologies for determining vegetative cover are not universal and vary among installations. These methods can be so labor-intensive and time consuming that repeated estimates per plot during the year become unrealistic (Althoff et al. 2004). Quantitative, accurate, and inexpensive techniques that do not require extensive technical skills are needed to estimate ground cover and vegetative damage on training lands.

Two methods commonly used to assess plant growth are estimates of cover and biomass production. Biomass estimates are more exact measures of how much growth has occurred within an area; however, the methods require the destructive harvest of plants and are prone to large yearly variations dependent on precipitation amounts. Cover estimates are often used to describe vegetative conditions because they do not involve clipping of plants, and are, therefore, less destructive than biomass production techniques. Plant density and frequency may also be used as additional growth measurements, with frequency representing plant community structure and plant density representing the number of plants per unit area (Stocking 1994).

Cover is an important ecological characteristic and is generally calculated as the percentage of ground surface covered by vegetation. Cover can be expressed in absolute terms (square meters/hectares) but is most often expressed simply as a percentage. Researchers use several types of cover to classify erosion potential, but the most common examples are foliar, canopy, ground, and basal covers. Foliar cover is the area covered by the aerial portions of plants, canopy cover is the area covered by the outer perimeter of foliage, ground cover is the percentage of ground covered by plants, litter, rocks and gravel at a site, and, basal cover is the area of ground covered by the basal (new growth) portion of the plants (NARSC 1996). The cover types that are most relevant to erosion potential are ground cover and basal cover, since these estimates reflect the amount of plant materials situated directly on the soil surface.

Visual plant cover estimates are often used because they are more rapid (Sykes et al. 1983). Visual methods estimate the percent of ground cover of different classes of vegetation within an area or quadrant. The percent cover in each vegetation class is then summed together to obtain a total estimate of plant cover. Aerial photography and Geographic Information System (GIS) vegetative layers are useful for overall resource surveys, but they are not detailed enough in their resolution to provide accurate estimates of cover. The simplest, most practical and least costly techniques for direct measure of vegetative cover are vertical photography and the use of a quadrant sighting frame (Stocking 1994). An analysis of digital photographs randomly taken to document vegetative cover is described and the results are compared with two other common methods, visual ground cover estimates and basal cover estimates using the point-intercept method.

The digital photography method described is less labor intensive than the point-intercept method, while providing a temporal record of ground cover conditions. Estimation of basal cover by this method produced the best results, especially in the early and late phases of the growing season when plant growth is more distinct from background colors. The method also allows for the standardization of ground cover estimates between sites, something that cannot be accomplished when using gross visual estimates.

APPENDIX B

PROJECT DETAILS AND DATA COLLECTION

For the purpose of testing the efficacy of using digital photography for ground cover estimations, photographs from two installations were obtained for analysis. Photographic documentation of vegetative conditions was obtained from Fort Hood, TX, and Fort Benning, GA. The analyses of the digital images determined the number of pixels that fall within certain color classes that represent vegetation, litter, or bare ground. Since data collection and analyses from each installation varied slightly, sampling procedures will be discussed separately.

Fort Hood, Texas

Fort Hood data were collected at regular intervals spaced 2,000 meters apart, based on a sampling grid laid out over a map of the installation (Figure B1). The sampling grid resulted in 136 sample points; however, access to one area was denied, resulting in a total of 135 points. A regular sampling interval was chosen over a random sampling interval in order to include all parts of the base with a similar sampling effort.

At each of the 135 points, three 100-meter long transects, spaced 50 meters apart, were sampled with three end points on a 3 by 3 grid centered at each transect. The field researcher sampled the end points of which were the nine subpoints described above. Grid points, and start and end points for each transect, were identified in the field using a handheld global positioning system (GPS) receiver (Garmin Etrex® series). At 0-, 50-, and 100-m intervals along the transect, a Nikon Coolpix® digital camera set on “basic” (low resolution) was used to take a picture of ground cover, within a 0.5 m^2 (0.701 x 0.701 m) quadrant, as described in Taylor (2001). At the end of each half of the transect, an estimate was made of the percent of the transect that was in various habitat categories: paved road, dirt road, tank trail, fire break, path, bare ground due to disturbance, natural bare ground, deciduous forest, juniper forest, grassland, herbaceous vegetation, water, and brush piles. The number of paved roads, dirt roads, tank trails, and paths were also counted for each 100-m transect.

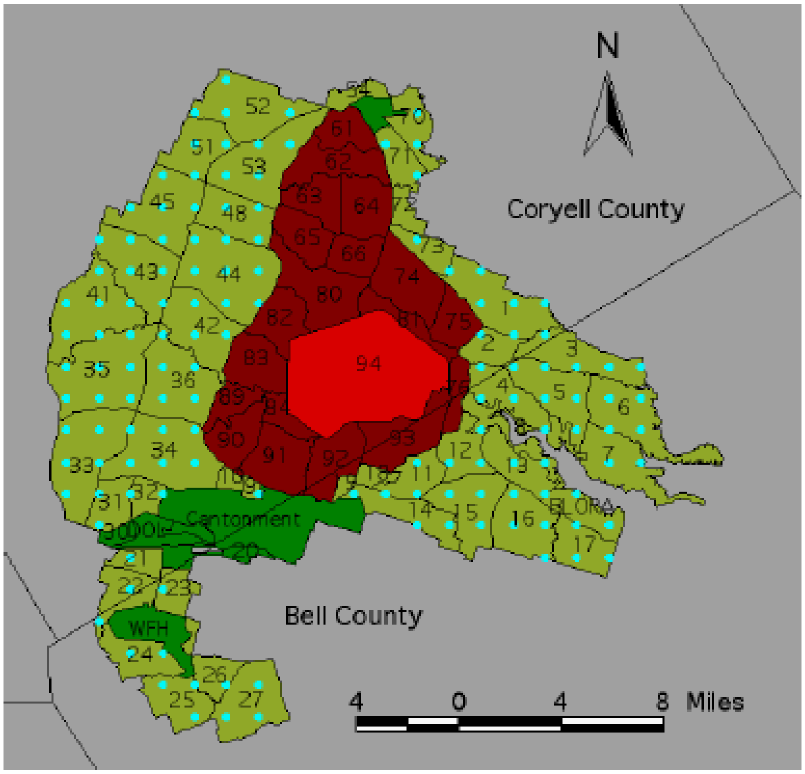


Figure B1. Map of Fort Hood (Bell and Coryell counties, Texas) showing urban areas (dark green), live fire area (dark red), permanently dudded (=impact) area (bright red), and other training areas (light green). The map is overlaid with a grid of light blue marks at 2000-m intervals in the other training areas. These marks represent sampling points (Taylor et al. 2003).

Photographs were later analyzed in Adobe Photoshop® by overlaying them with a 10 x 10 grid of points and scoring the substrate under each point (Figure B2). This scoring method produced an estimate of percent ground cover in various cover classes (grass, leaf litter, herbaceous vegetation, bare rock, bare soil, woody vegetation, and cactus). A total of 1215 images (9 images from each of the 135 sampling points) were scored by hand in this manner.

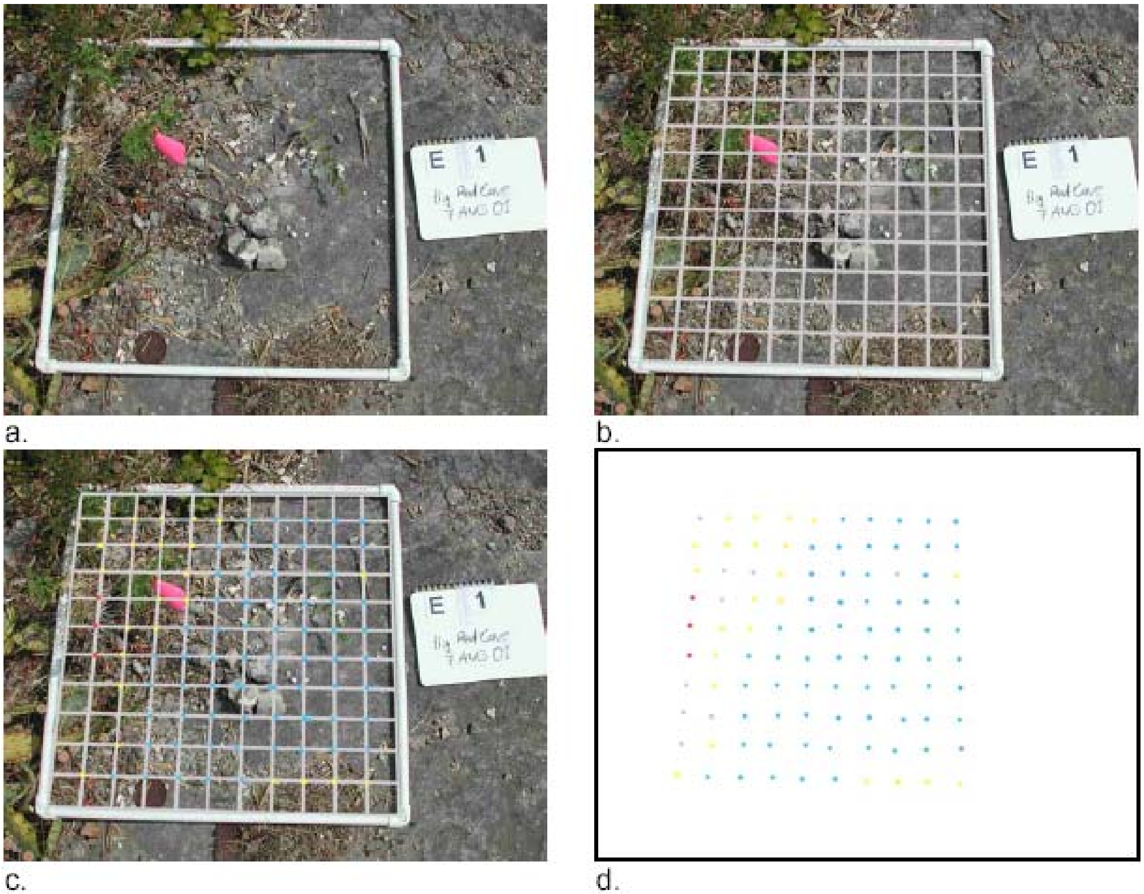


Figure B2. Quantifying ground cover near Big Red Cave, Fort Hood, TX, (a) Ground cover quadrant photo at Big Red Cave, imported into Photoshop, (b) The same image with a grid overlaid. There are 100 intersections in the grid (edges are not counted), which has been purposely distorted in Photoshop to account for the perspective view of the image. (c) Colored dots, corresponding to different cover classes (grass, bedrock, etc.) are added to a third layer in the Photoshop image file, (d) All layers except the colored dots (representing ground cover classes) have been turned off in Photoshop, and the dots are counted, by color, to give an estimate of percent ground cover for each cover class.

In addition to analyzing the ground cover images as described above, the vegetation classification, percent land cover, and distance to nearest road was created with Environmental Systems Research Institute (ESRI) ArcGIS. The 135 points used were spatially joined with a 1-m vegetation classification grid, which assigned vegetation classifications at each point with various vegetation classes: Juniper Forest, Live Oak Forest, Upland Deciduous Forest, North Slope Deciduous Forest, Alluvial Deciduous Forest, Post Oak Forest, Live Grassland/Herbaceous, Dormant Grassland/Herbaceous, Bare Ground, Urban Grassland, Hardscape/Roads, and “missing data.”

At each of the 135 points, a 3 x 3 array of subpoints 50 m apart was created. A circular area extending 25 m from the corners was established producing a disk with a radius of 95.658 m and area of 28,746.99 m^2 (2.875 hectares, 7.104 acres). New polygons were created based on 1-m U.S. Geological Survey digital orthophoto quadrangle. Polygons were drawn around trees, water, and bare ground, leaving the remaining area as grassland. Polygons were drawn slightly beyond the limits of the circle, but were clipped in a systematic method in order to avoid overlap. The polygons were dissolved for each circle and land cover type to create a unique land cover type for each grid. The area for each of these dissolved polygons was determined and divided by total area of the grid to calculate percent land cover for each type (Figure B3).

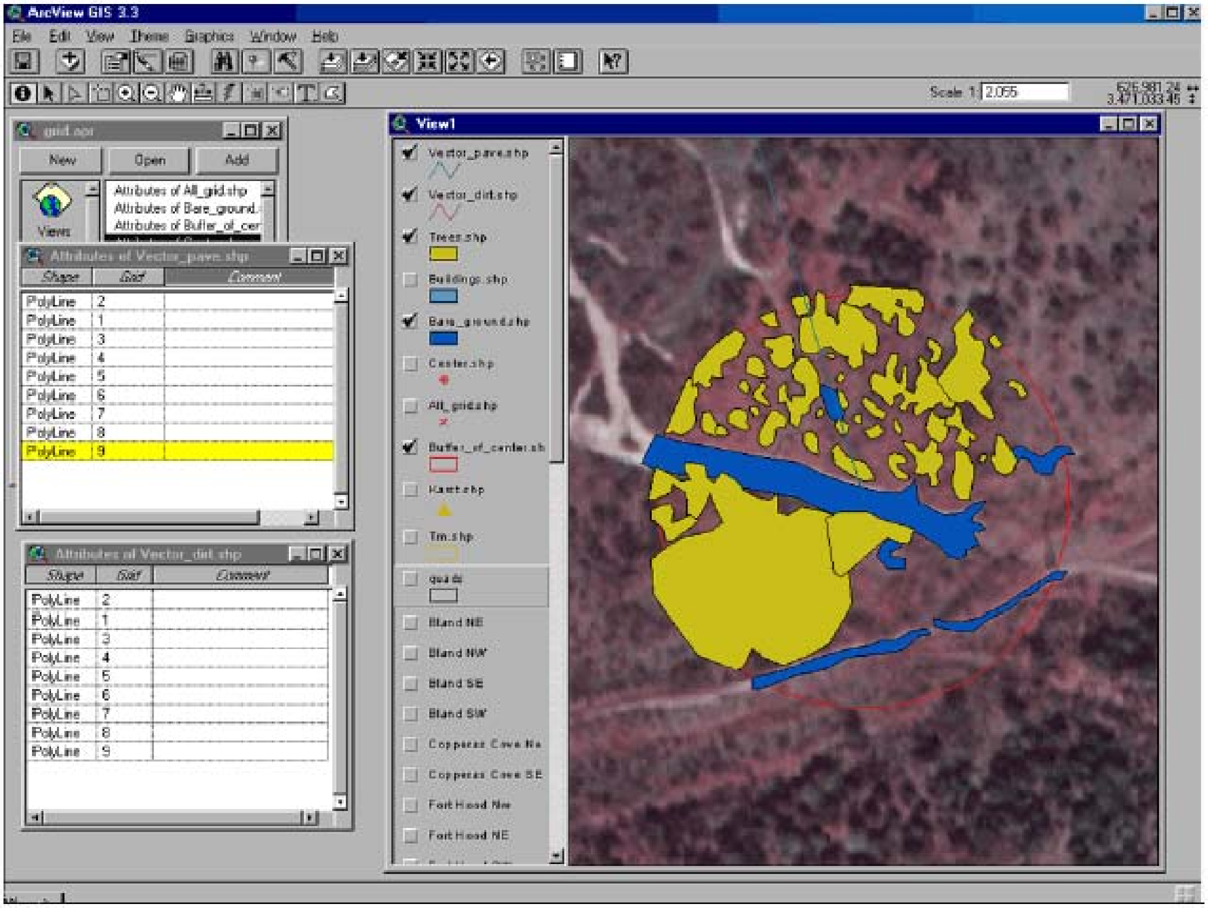


Figure B3. Screen snapshot of ArcGIS using aerial photography to create polygons. Blue polygons represent bare ground (including a dirt road), yellow polygons represent trees.

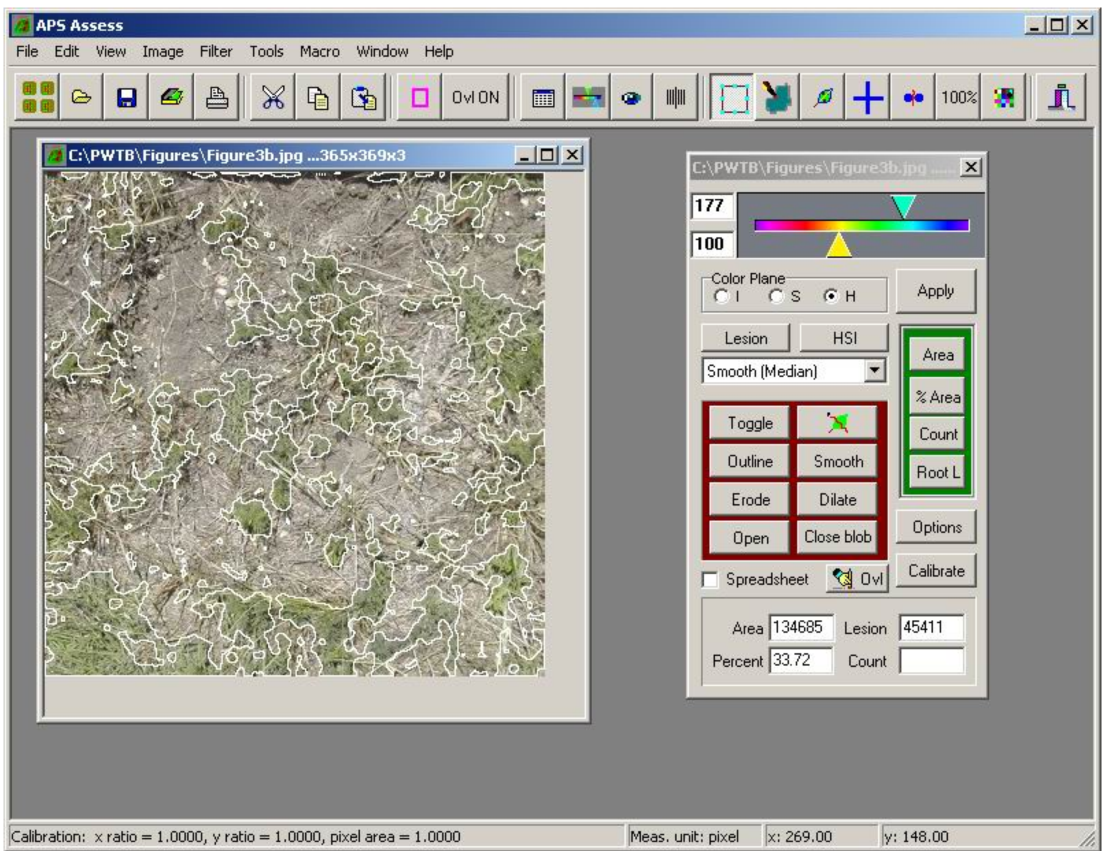
Fort Benning, Georgia

Data collection to compare vegetative cover estimates at Fort Benning was done during the final year of a 2-year study on land application rates of a soil amendment made from ground solid wastes (Fluff). Application rates of 0, 17.9, 35.8, 71.6, and 143 Mg of Fluff per hectare dry weight were incorporated into the top 15 cm of soil and seeded with big bluestem, Indian grass, switchgrass, and Virginia wild rye. Unseeded and seeded controls were used to compare differences between natural recovery and seeding following disturbance. Plots were 3.66 m x 4.88 m in area with 0.6-m buffers between plots in each block and 2.44 m buffers between blocks. Each study site was a randomized complete block with four replications, blocked by slope. Data collection consisted of species composition and basal cover estimates using a 10-point frame (Sharrow and Tober 1979), with 200 random points taken per plot. Five random digital images were taken within each plot with a Nikon Coolpix® digital camera set on “basic” (low resolution) using a 0.5 m^2 quadrant, as was done at Fort Hood.

A commercially available software program, *Assess* (Lamari 2002) was used to analyze digital images from both installations. *Assess* measures ground cover using the hue component of the color space within an image. The measurement represents pure color and is independent of intensity within each pixel. The software isolates the color of vegetation within the image and measures the area it occupies relative to the color of ground. Measurements using *Assess* are based on a sliding color bar that defines the color classes for each of the areas of interest (Figure B5). The settings for the color plane were determined from several trials of randomly selected photographs from the data set. The lower setting for the color space was set at a value of 100, while the upper setting was set at a value of 177. These settings isolate the hues within the photographs that represent vegetative growth. Photographs from Fort Hood and Fort Benning were cropped to the area within the quadrant to facilitate batch processing of the photographs during the analysis. The percentage of color that represents vegetative cover within the cropped area was recorded at the time of the analysis (Figure B5). Statistical analyses were performed using SigmaStat (v. 3.10, Systat Software, Inc., 2004). Level of significance for all statistical tests was set a priori at $\alpha \leq 0.05$.

a.

b.



c.

Figure B5. Ground cover digital image at Fort Hood showing uncropped version (a), cropped version (b), and *Assess* analysis (c).

APPENDIX C

RESULTS

Fort Hood, Texas

Fort Hood digital photos were analyzed to test the hypothesis that the *Assess* methodology is an effective way to estimate ground cover percentages across the installation. The results from the *Assess* method were compared with estimates made from grid-based analytical methods of images, Geographic Information System (GIS) and aerial photographs, and visual estimate methodologies.

Estimates of ground cover from the GIS method were calculated by summing the grassland and herbaceous plant classifications. The visual estimates were calculated from the estimated observed grasses that were documented along each transect. The *Assess* estimate was calculated using a color bar setting between 100 and 177, which defines color hues in the yellow to blue-green range as vegetative cover.

Mean values of each of the four ground cover estimates from the 135 sampling points at Fort Hood were compared using a One-way Analysis of Variance (ANOVA) test. An equal variance test of the data failed, so the nonparametric Kruskal-Wallace Analysis of Variance on Ranks was used to determine if the estimates were significantly different (Table C1). Since there were differences between median values of ground cover estimates, an all pairwise multiple comparison was done to isolate the groups that differ from the others (Table C2). The photo grid estimates differed from all other groups. This is most likely because the hand-scored estimates represent only 100 points within each photograph or a very limited portion of the entire quadrant.

Table C1. Kruskal-Wallis One Way Analysis of Variance on Ranks of Four Ground Cover Estimate Methodologies

Kruskal-Wallis

Group	N	Mean	Median	Std. Dev.	Std. Error
Visual Estimate	135	39.99	37.11	20.36	2.08
Assess Estmate	135	42.90	41.11	31.80	1.37
GIS Estimate	135	42.98	45.17	17.07	2.54
Photo Grid Estimate	135	79.86	82.00	69.83	1.26

H = 198.816 with 3 degrees of freedom; $P < 0.001$

Table C2. All Pairwise Multiple Comparison (Tukey) of Four Ground Cover Estimate Methodologies

Comparison	**Difference of Ranks**	**q**	**Significance P < 0.05**
Photo Grid vs. Visual	30973.50	17.08	Yes
Photo Grid vs. Assess	29213.50	16.11	Yes
Photo Grid vs. GIS	28073.00	15.48	Yes
GIS vs. Visual	2900.50	1.60	No
GIS vs. Assess	1140.50	0.63	No
Assess vs. Visual	1760.00	0.97	No

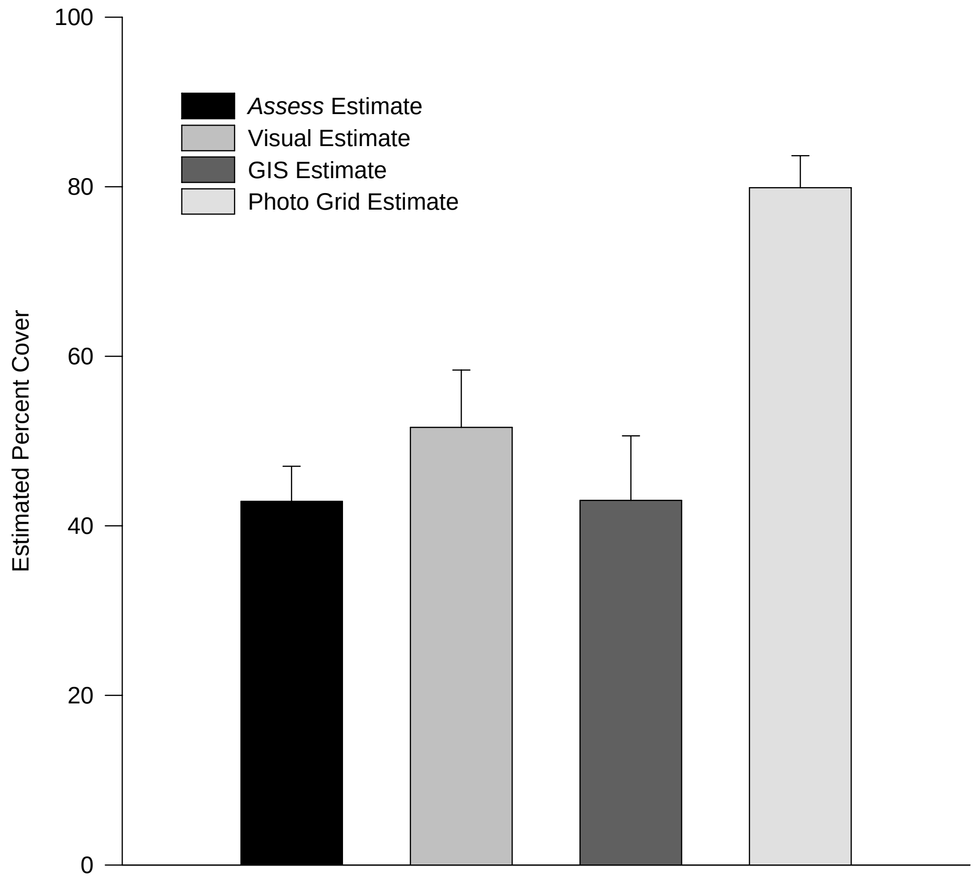


Figure C1. Comparison of median values from four ground cover estimates at Fort Hood, TX.

Median values from all other comparisons were not different (Figure C1); therefore, it can be concluded that the *Assess* methodology is the same as the visual estimates and the GIS estimates using aerial photographs. A Pearson Product Moment Correlation was also done to test if the data from each of the four estimates were correlated. The results of this test show that the *Assess* estimate is positively correlated to all of the other estimating methodologies. In addition, the photo grid method is positively correlated to the visual estimation method, and the GIS method is positively correlated to the visual ground cover estimates made at Fort Hood, Texas (Table C3).

Table C3. Pearson Product Moment Correlation Coefficients of Four Ground Cover Estimates at Fort Hood, Texas.

Comparison	**Correlation Coefficient**	**P < 0.05**
Assess vs. GIS	0.291	Yes
Assess vs. Photo Grid	0.252	Yes
Assess vs. Visual	0.316	Yes
Photo Grid vs. Visual	0.365	Yes
Photo Grid vs. GIS	0.161	No
GIS vs. Visual	0.815	Yes

Fort Benning, GA

The analysis at Fort Benning tests the assumption that the *Assess* methodology can be used to estimate basal cover. Basal cover, or the amount of cover attributed to the basal rooted parts of plants, is often used at Army installations as cover estimates for erosion control projects. Basal cover is a good indicator of vegetative health, since it is based on the percentage of growth within an area during a specific time period.

Basal cover was estimated using point-frame sampling techniques (Sharrow and Tober 1979) and mean values were calculated for each treatment (N=800) (Table C4). In addition to the point-frame estimations of basal cover, five random digital images were taken within a 0.75 x 0.75 quadrant in each plot for each treatment (N=20). The resulting mean values from the *Assess* analysis of the photographs were compared with the point-frame estimates using a *t*-test. The following treatments did not meet the normality of equal variance assumptions of the *t*-test, so the nonparametric Mann-Whitney Rank Sum Test was used to compare median values: CNR, 8T, and 32T (Table C5).

Comparisons of the point-frame estimate of basal cover were made for each treatment with the treatment averages from the *Assess* methodology. Results of this comparison show that there are no significant differences between the two methods (Table C5, Figure C2).

Table C4. Summary Data of Results From Plots for Each Treatment and Basal Cover Estimation Method

Treatment / Estimate	Plot 1	Plot 2	Plot 3	Plot 4	Mean	Median	Std. Deviation
CNR /Pnt. Frame	0.00	0.00	0.5	0.00	0.12	0.00	0.25
CNR / *Assess*	0.03	0.08	0.52	0.06	0.17	0.07	0.23
CR/Pnt. Frame	1.00	1.00	3.00	3.00	2.00	2.00	1.15
CR /*Assess*	0.34	0.15	2.46	3.94	1.72	1.40	1.81
8T /Pnt. Frame	7.00	7.00	4.50	4.00	5.62	5.75	1.60
8T /*Assess*	6.44	2.53	6.50	1.97	4.36	4.49	2.45
16T /Pnt. Frame	8.00	8.00	9.50	5.50	7.75	8.00	1.66
16T /*Assess*	8.01	8.87	10.57	12.71	10.04	9.72	2.08
32T /Pnt. Frame	12.00	12.00	8.50	17.00	12.37	12.00	3.50
32T /*Assess*	11.86	12.99	12.56	16.99	13.60	12.78	2.31
64T /Pnt. Frame	14.50	18.50	17.50	11.00	15.38	16.00	3.38
64T /*Assess*	13.96	15.08	11.83	15.14	14.00	14.52	1.55

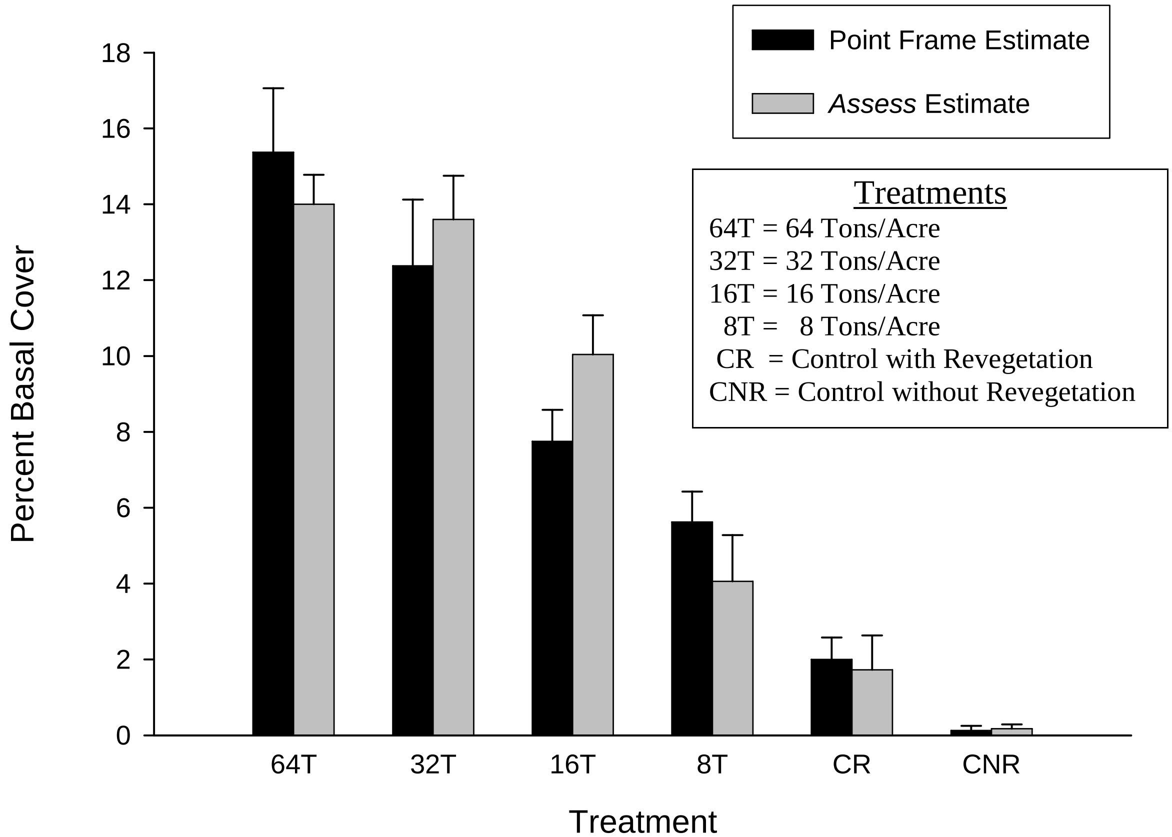


Figure C2. Comparison of mean values of Point Frame vs. *Assess* estimates of basal cover at Fort Benning, GA.

Table C5. Comparisons of Ground Cover Estimates in Each Treatment at Fort Benning, GA.

***t*-test Comparison**	**Diff of Means**	***t***	**P**	**Significant**
64T Point Frame vs. 64T *Assess*	1.370	0.738	0.488	No
16T Point Frame vs. 16T *Assess*	2.290	1.723	0.136	No
CR Point Frame vs. CR *Assess*	0.276	0.257	0.806	No
Mann-Whitney Rank Sum Test Comparison	**Diff of Medians**	**T**	**P**	**Significant**
32T Point Frame vs. 32T *Assess*	-0.778	16.00	0.686	No
8T Point Frame vs. 8T *Assess*	0.262	22.00	0.312	No
CNR Point Frame vs. CNR *Assess*	-0.066	13.00	0.193	No

Treatments

64T = 64 Tons/Acre
32T = 32 Tons/Acre
16T = 16 Tons/Acre
8T = 8 Tons/Acre
CR = Control with Revegetation
CNR = Control without Revegetation

APPENDIX D

SUMMARY

Vegetative cover is a critical factor in estimating soil erosion potential. The Universal Soil Loss Equation (USLE) requires an estimate of ground cover to calculate annual soil loss within a watershed (Wischmeier and Smith 1978). The Army Training and Testing Area Carrying Capacity (ATTACC) methodology uses erosion status to assess current and predicted land condition based on proposed training loads (Tweddale et al. 2000). ATTACC uses vegetative cover as defined by USLE (the C factor) to characterize land condition-ns as to the ability to support military training and testing activities in a sustainable manner.

Vegetative cover estimates are made in several ways, including visual estimates, point-frame transect methods, or deriving vegetative indices from satellite imagery. The methods most often used to obtain quantitative data, however, are generally expensive and time-consuming due to field methods that require replicate point frame sampling schema. Satellite imagery data are expensive to collect and deriving vegetative imagery from the data obtained is also costly. A cost-effective method to estimate vegetative cover for use in various erosion potential models would reduce costs of erosion control projects on U.S. Army training and testing lands.

The digital photo analysis method evaluated by this project represents a quick and inexpensive way to obtain quantitative ground cover estimates. Digital photography does not require any specialized equipment and can be obtained quickly by a single person. The use of digital imagery to estimate ground cover also provides an accurate documentation of land conditions over time. The advantages of using digital imagery to estimate ground cover are substantial, making the described image analysis method useful to military land managers.

The method is useful for estimating ground cover in a variety of situations. The Fort Hood analysis, for example, represents a nonhomogenous environment that is composed of bare rock, leaf litter, and varying soil types. The image analysis method used in this study does not differ from the more expensive and time-consuming GIS/aerial photograph analysis, visual estimates along transects and photographic grid (Taylor 2001) methods. The use of easily obtained digital photographs to estimate vegetative cover is a method that will save time when documenting and monitoring ground cover on military installations.

Finally, results from Fort Benning show that image analysis can be used effectively to estimate basal cover. Basal cover is the percentage of soil surface that is occupied by vascular vegetation; therefore, it is a good estimate of active plant growth in the area. Basal cover can be used to estimate plant production (Adler et al. 2005) and is a good indicator of erosion protection within many ecological systems. Basal cover is normally estimated using point-transect methods that require time-consuming field techniques (Althoff 2004), limiting the number of samples that can be made during the growing season.

The analysis of digital photographs using the *Assess* methodology is a very quick and accurate way to estimate basal cover, as shown by the results of this study. The estimates made from the digital photographic analyses were the same as estimates from point-transect methods within treatment groups (Figure C2). The collection and analysis of the photographs was estimated to take approximately 80 percent less time than the point-frame method, and the results were not significantly different.

Based on the results obtained from Fort Hood and Fort Benning, analysis of digital photographs using the *Assess* software is an effective way to estimate vegetative cover and basal cover. The method is best suited for basal cover estimates later in the growing season. Photographic analysis can easily determine the amount of vascular growth in an area, especially when the plants are in the latter part of the growing season. It is assumed that similar results would be obtained during the early stages of the growing season, but further study is needed. Overall, the results of this study show that the use of digital image analysis to determine vegetative cover can be an accurate, cost-effective way to monitor ground cover on Army training lands.

APPENDIX E

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