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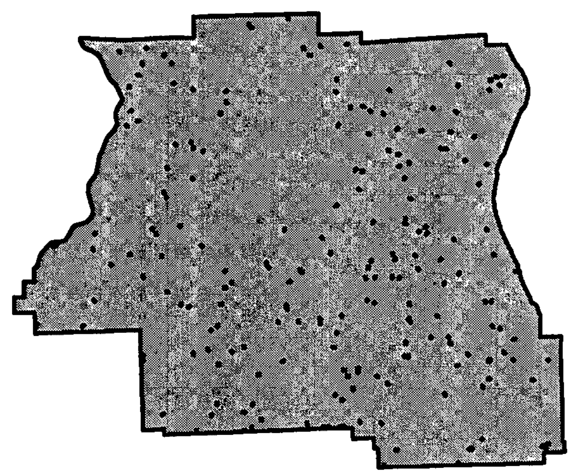
# Correlation of Land Condition Trend Analysis (LCTA) Rangeland Cover Measures to Satellite-Imagery-Derived Vegetation Indices

by
Gary M. Senseman, Scott A. Tweddale, Alan B. Anderson, and Calvin F. Bagley

Using field data from the U.S. Army's land inventory and monitoring program, a study was conducted to examine the utility in estimating the quantity of vegetation cover with satellite imagery across a large and complex rangeland. The U.S. Army's Yakima Training Center (YTC), WA, was studied for this investigation. The Land Condition Trend Analysis (LCTA) program at YTC has 202 permanent plots located in a randomly stratified manner across the installation. The principle measures taken along the transects were canopy cover and ground cover. These analyses used Landsat Thematic Mapper imagery collected in May and August of 1992. The satellite data coincided with the beginning and end of the field data collection period and were used to derive various vegetation indices (VIs), including the Ratio VI, the Transformed VI, the Soil Adjusted VI, and the Modified Soil Adjusted VI. Analysis of correlation of rangeland cover measures and satellite-imagery-derived VIs were performed. Correlation between the VIs derived from the May image and the cover measures were found to be stronger than those between the August image and cover measures.



LCTA transects at Yakima Training Center, WA.

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# Foreword

This study was conducted for Directorate of Environmental Programs under Project 4A162720A896, "Environmental Quality Technology"; Work Unit EN-TL6, "Integrated Natural and Cultural Resources Data Analysis" and Work Unit EN-TS5, "Comparative Data Acquisition Alternatives for Training Area Management." The technical monitor was Victor E. Diersing, DAIM-ED-N.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigators were Scott A. Tweddale and Alan B. Anderson. Gary M. Senseman is a Research Associate, Colorado State University. Calvin F. Bagley is Associate Director, Center for Ecological Management of Military Lands, Colorado State University. The Yakima Training Center Environmental and Natural Resources Directorate provided data, and William Sprouse, Colorado State University, provided database support for this project. Dr. David J. Tazik is Acting Chief, CECER-LL-N, and Dr. William D. Severinghaus is Operations Chief, CECER-LL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

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# 1 Introduction

## Background

Military training and testing installation land managers face the difficult task of sustaining natural resources in order to provide a realistic training environment and to comply with environmental regulations. For managers to make informed land management decisions, accurate resource characterization and assessment of landscape condition and trends is necessary. This effort must occur in an era characterized by decreasing funds, a shrinking work force, increasing demands on natural resources to support military training, and legal requirements to be good stewards of the public trust.

Ecological field surveys alone are cost prohibitive and only represent a sample of the landscape. Therefore, application of all available technologies is needed to optimize the effectiveness of natural resource management on military installations. Remotely sensed data are thought to be a more cost-effective source for augmenting ecological surveys. However, a relationship, or correlation, between remotely sensed data and ecological field surveys must be established before remotely sensed data can be translated to ecological information of use to resource managers on training and testing installations.

The U.S. Army has implemented a standard natural resource assessment and monitoring program on many of its installations. This program, the Land Condition Trend Analysis (LCTA), was designed to assist in evaluating the capability of land resources to support multiple-use demands on a sustained basis and monitor changes over time (Tazik et al. 1992). The LCTA program is a natural resource inventory and monitoring program consisting of permanent plots that are measured annually. This report investigates correlation of ecological variables, collected as part of the LCTA program, with various remotely sensed vegetation indices.

## Objectives

The application of vegetation indices to this case is unique in that it is an application of the technology outside of the well controlled experimental conditions in which the indices were developed. Field data from this inventory and monitoring program were collected throughout the growing season. This asynchronous relationship of field data to remotely sensed data raises the concept of an optimal image collection date. LCTA data is a collection of several descriptive vegetation measures. When combined with the applicable vegetation indices and multiple image collection dates, these measures create a matrix of combinations of vegetation index, image date, and cover measure.

The first objective of this study was to identify the relationship among cover measure, vegetation index, and image date through investigation of their measure of linear correlation. The second objective was to use vegetation indices to create improved vegetative cover maps of Yakima Training Center (YTC), Washington for ongoing carrying capacity and erosion modeling efforts.

## Approach

A literature survey was conducted to identify vegetation indices that have been used successfully to estimate vegetative cover. Based on the literature survey, several vegetation indices were selected for evaluation with LCTA field data. LCTA data measures that are important to vegetation and erosion modeling efforts and that would potentially correlate well with vegetation indices were identified. Using the selected vegetation indices and LCTA measures, correlation analysis identified the vegetation indices and field ground-truth measures with the strongest relationship. Correlation analysis was used also to assess the relative importance of topographic normalization of images and the image acquisition date. Finally, regression analysis techniques were used to create cover maps for YTC based on results of the correlation analysis.

## Scope

The techniques and vegetation indices described in this report are applicable to other installations. However, the strength of the relationships between specific vegetation indices and LCTA measures are likely to vary between installations depending on vegetative and soil characteristics of each installation. Studies are under way to investigate the relationship between vegetation indices and LCTA measures at additional installations and ecoregions. Studies are also under way to assess the importance of coordinating field data collection dates and image acquisition dates as a means of improving the strength of the relationships between image and ground-truth data.

## Mode of Technology Transfer

It is recommended that the data processing techniques described in this report be used by Army installation land managers in modeling efforts such as soil loss and carrying capacity estimation that require the extrapolation of LCTA vegetative cover data across the installation as inputs to these models.

# 2 Correlation of Imagery Indices and Field Measures

## Background

Attempts to correlate vegetation characteristics with original spectral bands collected by remote sensors such as the Landsat satellite's Thematic Mapper have proven to be less than successful. However, research indicates that correlation of vegetation characteristics with ratio or linear transformations of the original spectral bands produces better results. These ratio and linear transformations are commonly referred to as vegetation indices.

A vegetation index is derived from discrete bands of electromagnetic reflectance commonly imaged by space-based sensors such as the Thematic Mapper. Transformation of pixel reflectance values from the satellite image into a new value produces the vegetation index. Each pixel in the derived index represents a relative amount of some vegetation characteristic, such as above-ground green biomass or percent cover, depending on the index used.

The purpose of image-depicted vegetation indices is to show relative differences of some vegetation characteristic. The usefulness of a vegetation index can be increased if it is calibrated or correlated with ground-based data, which results in a mechanism to estimate biophysical aspects of the ground surface.

Linear regression analysis is one approach to calibrating a vegetation index with field-based measures of the vegetation. This process most commonly involves taking a representative sample of locations within the area imaged and determining the relationship of the vegetation index values and the field-based measures. Several methods can be used to determine the relationship between the vegetation characteristic and the vegetation index value. The simplest and probably most common approach is to use a linear model and a least-squares fitting algorithm.

## Correlation With Common Vegetation Indices

Most vegetation indices are transformations based on the near infrared and red portions of the electromagnetic spectrum. Research for this study explored the use of the simple infrared/red (IR/R) Ratio Vegetation Index, the Transformed Vegetation Index (TVI), the Soil Adjusted Vegetation Index (SAVI), the Modified SAVI (MSAVI), and the PD54.*

### *Ratio Vegetation Index*

Perhaps the simplest of these indices is the Ratio Vegetation Index, which is the ratio of red and near-IR spectral bands (Lillesand and Kiefer 1987). An early example of the application of a Ratio Vegetation Index correlated the vegetation index with standing crop biomass($g/m^2$) of undisturbed shortgrass prairie consisting primarily of blue grama grass (*Bouteloua gracilis*) (Pearson and Miller 1972). Plots 1/4 $m^2$ were the sampling units in this case. A relationship was found between green biomass and the spectral reflectance.

### *Normalized Difference Vegetation Index*

Probably the most commonly applied vegetation index is the Normalized Difference Vegetation Index (NDVI). The NDVI and many other indices were used in a study to determine relationships between spectral reflectance and vegetation canopy characteristics such as above-ground biomass, leaf water content, and chlorophyll content (Tucker 1979). Tucker used clipped vegetation plots of prairie grass that consisted primarily of blue grama. For one date in this multidate study, high coefficients of determination of a simple linear regression were found with NDVI and total wet biomass, total dry biomass, leaf water content, dry green biomass, and total chlorophyll. A linear relationship has also been established between NDVI and a Leaf Area Index of slash pine (Curran, Dungan, and Gholz 1992). Franklin, Duncan, and Turner (1993) found that for NDVI, among other indices, sunlit portions of a canopy and soil had similar index values.

### *Transformed Vegetation Index*

The TVI is a modification of NDVI accomplished by taking the square root and adding a constant of 0.5 (Tucker 1979). The transformation results in only positive values and the variances of the ratio are proportional to mean values. The TVI has been found to be correlated to the amount of green biomass found in a pixel

* PD54 - Perpendicular Difference Vegetation Index. The 54 refers to bands on the Landsat MSS sensor.

(Lillesand and Kiefer 1987). Also, Tucker (1979) compared the TVI with the same variables as he did with the NDVI and obtained slightly higher coefficients of determination for the same variables.

### *Soil Adjusted Vegetation Index*

Several attempts have been made to develop vegetation indices that minimize variance of the spectral reflectance due to background soil type. The objective is to isolate the portion of the reflectance attributable to differences in the vegetation. Two types of indices have come from this effort: (1) vegetation indices that require the use of constant value in the equation to account for variance due to soil and (2) vegetation indices that require a defined line of soil in the reflectance signal. A soil line is a line or plane in n-dimensional spectral space that passes through imagery pixels that are completely void of vegetation (i.e., bare ground). In general, pixels increasingly distant from the soil line in a spectral space represent a relative increasing vegetation amount, cover, or vigor.

The SAVI, introduced by Huete in 1988, attempts to account for variation in soil background. The key to the SAVI is the equation's soil constant, L. L is used to minimize the variability due to soil and differs depending on the general density of vegetation. In introducing the SAVI, Huete (1988) correlated SAVI with a Leaf Area Index of broad-leaf cotton and above ground biomass of narrow-leaf grass test plots.

### *Modified SAVI*

The MSAVI (Qi et al. 1994) is a modification of Huete's original SAVI. MSAVI attempts to further account for differences in soil background by replacing the constant L with a dynamic soil-adjusting factor. The MSAVI was applied to a cover measure of cotton and was demonstrated to better account for soil variability than SAVI on cotton field test plots (Qi et al. 1994).

### *Perpendicular Vegetation Index (PVI) and PD54 Index*

Many of the vegetation indices require the use of a soil line; PVI (Richardson and Wiegand 1977) and PD54 (Pickup, Chewings, and Nelson 1993) are relevant examples. The method used to define the soil line makes these indices difficult to use. In many cases, including the PVI, the soil lines are defined with ground radiometers. The airborne/satellite data are then calibrated with the radiometer data. Operationally, this makes using these indices very difficult. However, the PD54 and some other soil-line-based vegetation indices allow the soil line to be determined from within the satellite image itself. Derivation of the PVI for regression with sorghum resulted in a coefficient of determination for PVI and Leaf Area Index of sorghum, 0.81; for PVI and sorghum crop cover, 0.68; for PVI and sorghum crop cover in shadow, 0.38; and for PVI and sorghum plant height, 0.79 (Richardson and Wiegand 1977).

Pickup, Chewings, and Nelson (1993) derived the PD54 vegetation index, which differs from the other indices presented thus far in that it relies on the green and red portions of the electromagnetic spectrum. This index differs also from the other soil-line-derived indices in that the soil line may be derived through inspection of the satellite data. Pickup, Chewings, and Nelson (1993) applied their vegetation index to percent cover in arid rangelands of Australia. Satellite data were collected on two dates roughly 7 weeks apart with rain occurring several weeks before the second collection data. The results were a coefficient of determination of 0.86 for the data collected on the latter date; of 0.78 for the first data collected; and of 0.87 for all data combined.

# 3 Study Area

## Geographic Location

The Yakima Training Center is in south central Washington (Figure 1) on the eastern slope of the Cascade Mountain range, approximately 11.2 km northeast of the city of Yakima (46° 40' 38"N 120° 27' 10' W). The Center was established in 1941 as an anti-aircraft artillery range. Before being developed as a military installation, the area included several ranches and silica mines. Much of the surrounding area contains diversified agriculture and undeveloped Federal and private lands. Located in southern Kittitas and northeastern Yakima counties, YTC is bordered by the Saddle Mountains on the north and Yakima Ridge on the south; Umtanum Ridge runs through the center. Elevations range from 121 m to 1280 m, and the installation covers approximately 106,704 hectares.

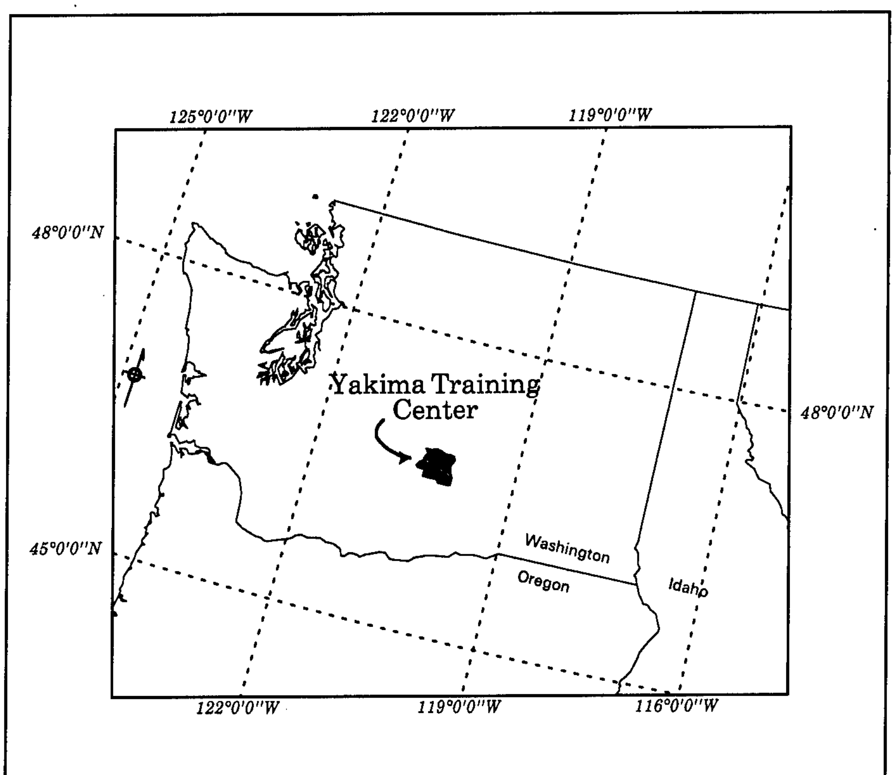


**Figure 1. Location map of study area.**

## Soil and Vegetation

The soils of the study area developed from parent material deposited during past glaciation and from material brought in by Pleistocene floods that carved the Columbia River Valley. These soils are extremely complex. Forty-eight series have been identified from five suborders (unpublished Soil Survey of the Yakima Training Area 1991). The soils of the YTC are underlain by basalt that flowed from large fissures or rifts on the surface and spread in all directions. Four east-trending ridges were formed when the basalt was slowly uplifted and folded. Soils on hill-slopes, ridges, and canyon slopes are generally stony silt loam, stony clay loam, and silt loam. Soils in the valley bottoms are generally silt loam. Most of the soils are well drained, and the vegetation of the area is described as a sagebrush steppe.

# 4 Field Data

For this study, a line transect was used to obtain two measures of cover: ground and canopy (aerial). Cover is defined as the basal area at the ground surface or as the vertical projection of the crown or shoot areas of a species. Cover is often expressed in percent or fraction of the area measured (Mueller-Dombois and Ellenberg 1974; Stoddart, Smith, and Box 1975).

Field data locations were selected using a stratified random design based on landcover and a digital soil survey map (Warren et al. 1990). The landcover map was derived from SPOT (Systeme Probatoire pour l'Observation del la Terra) multispectral data (wavelengths = green 0.50-0.59 µm, red 0.61-0.68 µm, near infrared 0.79-0.89 µm) using a 19 category unsupervised classification. Data processing was accomplished with a geographic information system (GIS). Random points on a U.S. Geological Survey (USGS) 7.5-min quadrangle were allocated to polygons based on the stratification (Figure 2).

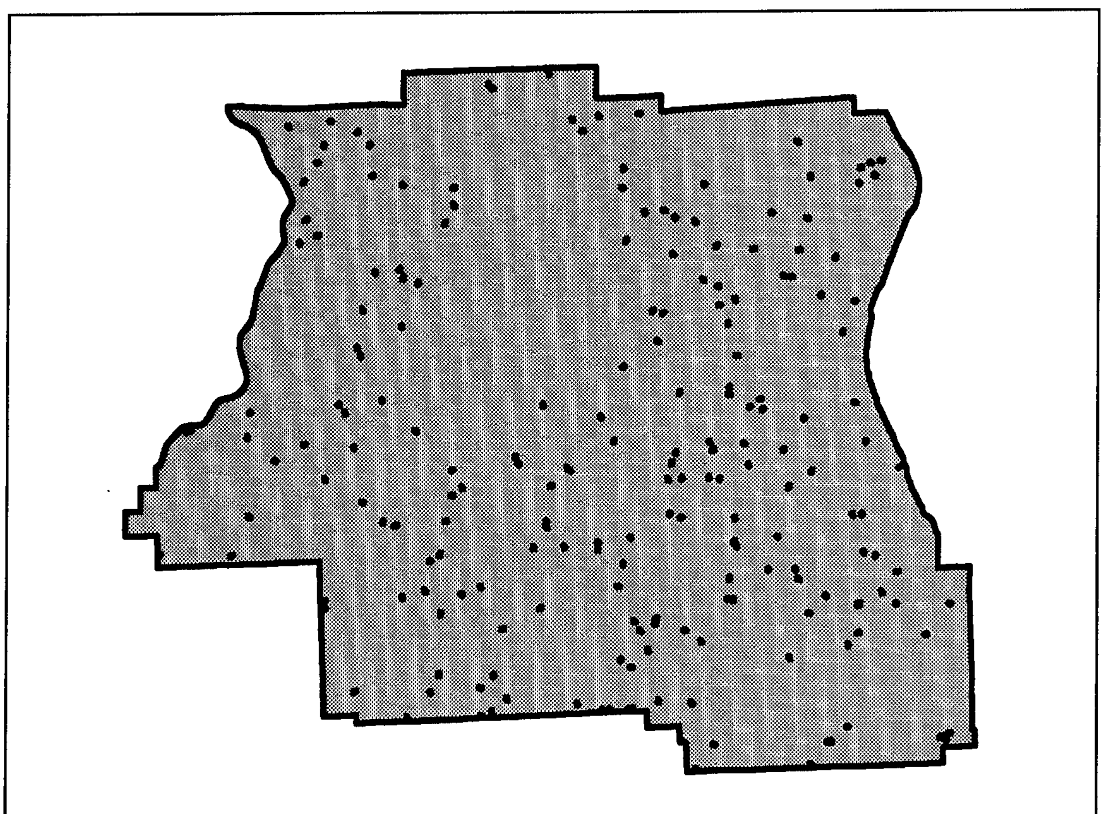

Figure 2. LCTA transects at YTC.

In the field, points were marked with a metal pipe and flange. This pipe identifies the beginning of the 100-meter line transect that forms the central axis of an LCTA plot. The azimuth of the plot was determined randomly making sure to remain inside the landcover/soil polygon for the entire 100-m length. A 100-m measuring tape was attached to the beginning stake and extended along the chosen azimuth. Canopy cover, ground cover, and military-related disturbance were measured using a point-intercept method (Bonham 1989) along the transect at 1-m intervals. One hundred points were sampled along the measuring tape beginning at the 0.5-m point and continuing at 1-m intervals for the length of the plot. A measuring rod was held vertically with the tip placed on the ground at each interval. Ground cover was then measured at the point. Only material in contact with the center tip of the measuring rod was recorded. Ground cover points were categorized into one of six categories: bare ground, gravel, rock, litter (forb, grass, or shrub), dead wood, and basal cover (identified by species). A vertical measure was made to assess canopy cover.

Using the same measuring rod, vegetation contacts were measured at 1-decimeter intervals, identifying each contact by species. Canopy cover was recorded only if the vegetation appeared to intercept the measuring rod. From these two cover measures, six summary statistics were calculated for correlation with the vegetation indices. The summary measures are perennial canopy cover (CCPER), annual and perennial canopy cover (CCTOT), canopy cover total hits (TOTHIT), ground cover-bare ground (BG), ground cover-plant cover (PC), and USLE-C factor (USLE-C). Field measurements for this analysis were collected starting in June 1992, and completed by August 1992. A global positioning system (GPS) using differential correction was used to collect precise location data for each plot.

# 5 Image Processing

Landsat Thematic Mapper satellite imagery acquired on 31 May and 3 August 1992 were used in this study. Both images were georeferenced to USGS 7.5' quadrangles with an overall root mean square (RMS) of less than ½ pixel. The data were resampled to the Universal Transverse Mercator (UTM) projection. The satellite data were converted to reflectance.

To analyze the correlation of LCTA cover measures with satellite-derived vegetation indices, it is necessary to extract pixels from the imagery that correspond spatially to the location where LCTA field data were collected on the ground. Positional accuracy of both the image pixels and corresponding LCTA plots is critical to ensure spatial correspondence between the two data sets. Each LCTA transect was accurately located in the field using GPS technology with differential correction.

Coordinates of LCTA data define an endpoint of a line transect. Based on this point location and the azimuth, a line representing the central axis of each plot was created in the GIS database and associated with corresponding pixels in the vegetation index image. Depending on the orientation of each transect, approximately 3 to 5 pixels of imagery corresponded to each 100-m-long LCTA transect (see Figure 3).

Although data were collected every 0.5 m along a 100-m LCTA transect in the field, a single summary value for each cover measure for each transect was derived and used as the input into the correlation analysis. Similarly, although each transect typically crossed through approximately 3 to 5 pixels of raster imagery, a single mean value of the vegetation index of interest for all of the pixels traversed by the transect was used in the correlation analysis.

USACERL researchers were able to derive the Ratio Vegetation Index, TVI, SAVI, and MSAVI, but were unsuccessful in deriving the PD54 vegetation index because of the difficulty in identifying pixels of total bare ground, which were necessary to identify a defensible soil line. The soil line is a necessary component of the PD54 vegetation index because each pixel's index value is based on its perpendicular distance from the soil line.

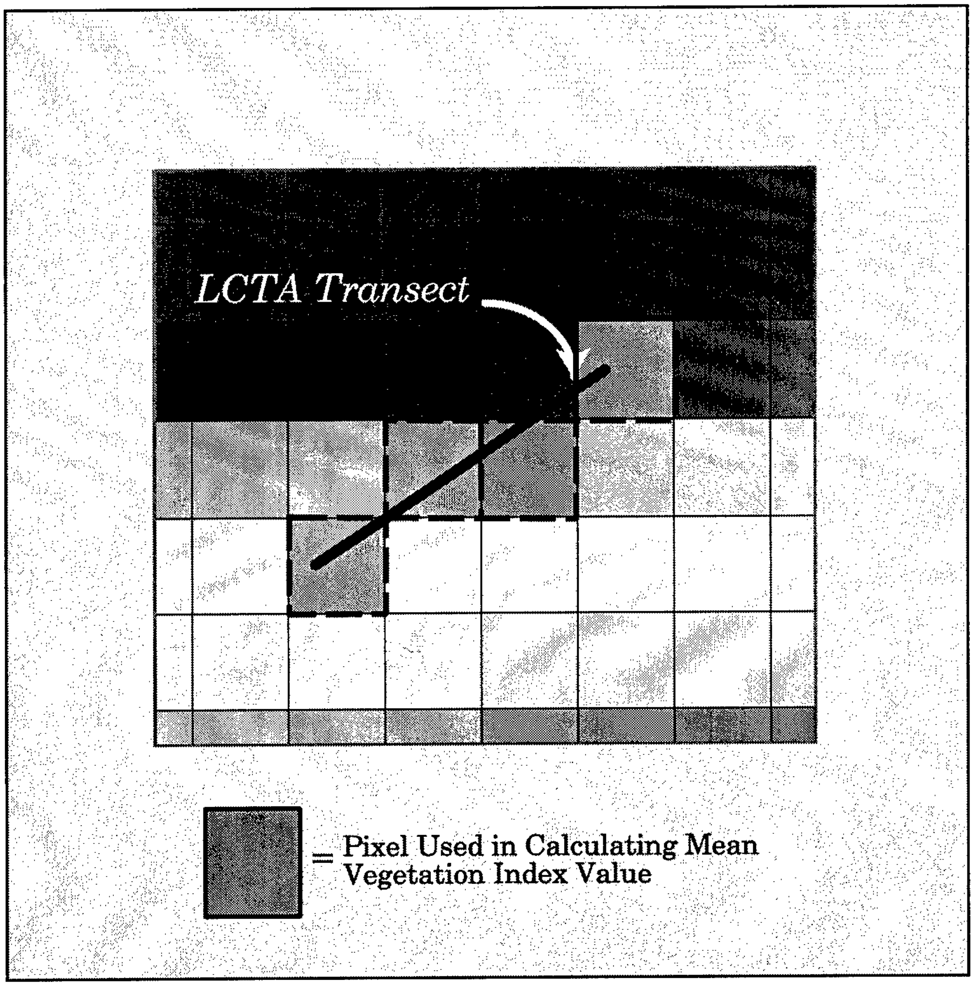


Figure 3. Extraction of imagery data.

# 6 Correlation and Regression

To determine which LCTA data best correlate with imagery-derived vegetation indices, six measures were identified for inclusion in the correlation study (Table 1). These data can be grouped into three distinct sets. The measures CCPER, CCTOT, and TOTHIT are counts made from the aerial cover measures and can be considered a group. Bare ground (BG) and plant cover (PC) can be considered another distinct group of data as measurements derived from ground cover. The third group is comprised of the USLE-C* measure and is a derivation from several LCTA measurements.

The four vegetation indices examined (Table 1) can be grouped into two categories. The first category contains the IR/R Ratio Vegetation Index and TVI. The second category of indices includes the SAVI and MSAVI. The second category differs from the first in that the indices in this category attempt to account for variability in background soil reflectance.

**Table 1. Descriptions of terms used.**

| Term | Description |
|---|---|
| *Vegetation indices* | |
| Ratio | IR/R vegetation index |
| TVI | Transformed vegetation index |
| SAVI | Soil adjusted vegetation index |
| MSAVI | Modified soil adjusted vegetation index |
| *Data measures* | |
| CCPER | Canopy cover - perennial |
| CCTOT | Canopy cover - perennial and annual |
| TOTHIT | Canopy cover - total hits |
| BG | Ground cover - bare ground hits |
| PC | Ground cover- plant cover hits |
| USLE-C | Universal Soil Loss Equation C factor |

A total of 202 LCTA plots existed in 1992. However, the number of plots used in the correlation study varied due to either the LCTA data being unavailable or plots being obscured by clouds when the satellite image was acquired. The sample size for the May image was 189. The sample size for the August image was 200.

* The Universal Soil Loss Equation (USLE) is an empirical model used to estimate soil erosion rates (Wischmeier and Smith 1978). The cover factor (C) in the soil loss equation is the ratio of soil loss from an area with specified cover to that of an identical area in tilled continuous fallow. C factor values can be estimated using LCTA ground and aerial cover data (Warren et al. 1991).

## Correlation Analysis

A correlation measure, Pearson's Product Moment (*r*), was calculated for each combination of vegetation index and LCTA measure to determine which field measurement best correlated with which imagery-derived index (Conover 1980). The correlations from the May image and LCTA data are summarized in Table 2. For the first group of field data, the differences in correlations between CCPER and CCTOT are small, and correlations are among the strongest correlations in the matrix. From the second group, BG has a correlation equal to the correlations in the first group of LCTA data. The third group, the USLE-C cover measure, also has a strong correlation. The strength of the correlations varies little between vegetation indices.

Table 3 summarizes the correlations from the August image. These correlations are much lower than those found in the May image. The differences between the correlations of the LCTA data and the August vegetation indices are similar to those found between the LCTA data and the May vegetation indices. The LCTA variables CCTOT and CCPER had the strongest correlations. In August, the USLE-C measure showed a stronger correlation with the vegetation indices than did the BG measure. Again, little difference was found in the strength of correlations between vegetation indices.

Table 4 summarizes correlations from the LCTA cover measures and the MSAVI. The correlations for MSAVI are summarized because this vegetation index consistently faired as well or outperformed the other indices. As seen in Table 4, the

**Table 2. Correlation with indices derived from the May image.**

| | CCPER | CCTOT | TOTHIT | BG | PC | USLE-C |
|---|---|---|---|---|---|---|
| **Ratio** | 0.63 | 0.63 | 0.56 | -0.63 | -0.08 | -0.60 |
| **TVI** | 0.64 | 0.64 | 0.58 | -0.63 | -0.07 | -0.62 |
| **SAVI$_{(L=0.5)}$** | 0.63 | 0.64 | 0.58 | -0.63 | -0.07 | -0.61 |
| **MSAVI** | 0.63 | 0.65 | 0.58 | -0.63 | -0.07 | -0.62 |

**Table 3. Correlation with indices derived from the August image.**

| | CCPER | CCTOT | TOTHIT | BG | PC | USLE-C |
|---|---|---|---|---|---|---|
| **Ratio** | 0.43 | 0.42 | 0.35 | -0.39 | -0.05 | -0.42 |
| **TVI** | 0.43 | 0.42 | 0.35 | -0.39 | -0.05 | -0.42 |
| **SAVI$_{(L=0.5)}$** | 0.43 | 0.43 | 0.35 | -0.39 | -0.05 | -0.42 |
| **MSAVI** | 0.43 | 0.43 | 0.35 | -0.39 | -0.04 | -0.42 |

Table 4. Correlations of cover measures with MSAVI.

| | May | August |
|---|---|---|
| CCPER | 0.63 | 0.43 |
| CCTOT | 0.65 | 0.43 |
| TOTHIT | 0.58 | 0.35 |
| BG | -0.63 | -0.39 |
| PC | -0.07 | -0.04 |
| USLE-C | -0.62 | -0.42 |

vegetation indices derived from the May image had much stronger correlations than those derived from the August images. The strongest correlations come from the May image where CCTOT and MSAVI had a correlation of 0.65. From the ground cover measures, BG showed a strong negative correlation of -0.63 with the May MSAVI. The LCTA-derived USLE-C measure had a strong negative correlation of -0.62 with the May MSAVI. The LCTA cover measure PC had very little correlation with any of the vegetation indices from either date of the satellite data.

Scatter plots of each combination of cover measure and MSAVI for each image date are shown in Figures 4 and 5. The plots show the relationship between the cover variables and the MSAVI. The correlation measures indicate several of the cover variables have fairly strong linear correlation with the MSAVI derived from the May satellite data, and this correlation is supported by viewing the scatter plots. The correlation measures between the cover variables and the August MSAVI indicated a weak linear relationship, which is supported by the scatter plots. Of particular note is the scatter plot for the PC (Figures 4 and 5). This plot shows the lack of a linear relationship to the MSAVI as indicated with the correlation measure. The lack of correlation is because the PC values for many of the transects were zero.

Correlations between vegetation indices derived from topographically normalized images and LCTA measures were also calculated. These correlations were very similar to the correlations from the raw May and August images with respect to the strength of the correlations. Some slight increases in the strength of the correlations were observed for several variable combinations.

## Linear Regression

A least-squares regression was fit using the May MSAVI as the independent variable and the LCTA CCTOT measure as the dependent variable so that CCTOT estimates for each of the remaining pixels of the image could be estimated to produce a spatial data layer of CCTOT. This bivariate combination was used because it had the strongest linear correlation. Figure 4 shows the regression line for the MSAVI and CCTOT regression. The coefficient of determination for the regression was 0.42 with a residual error of 13.21. Similar least-squares regressions

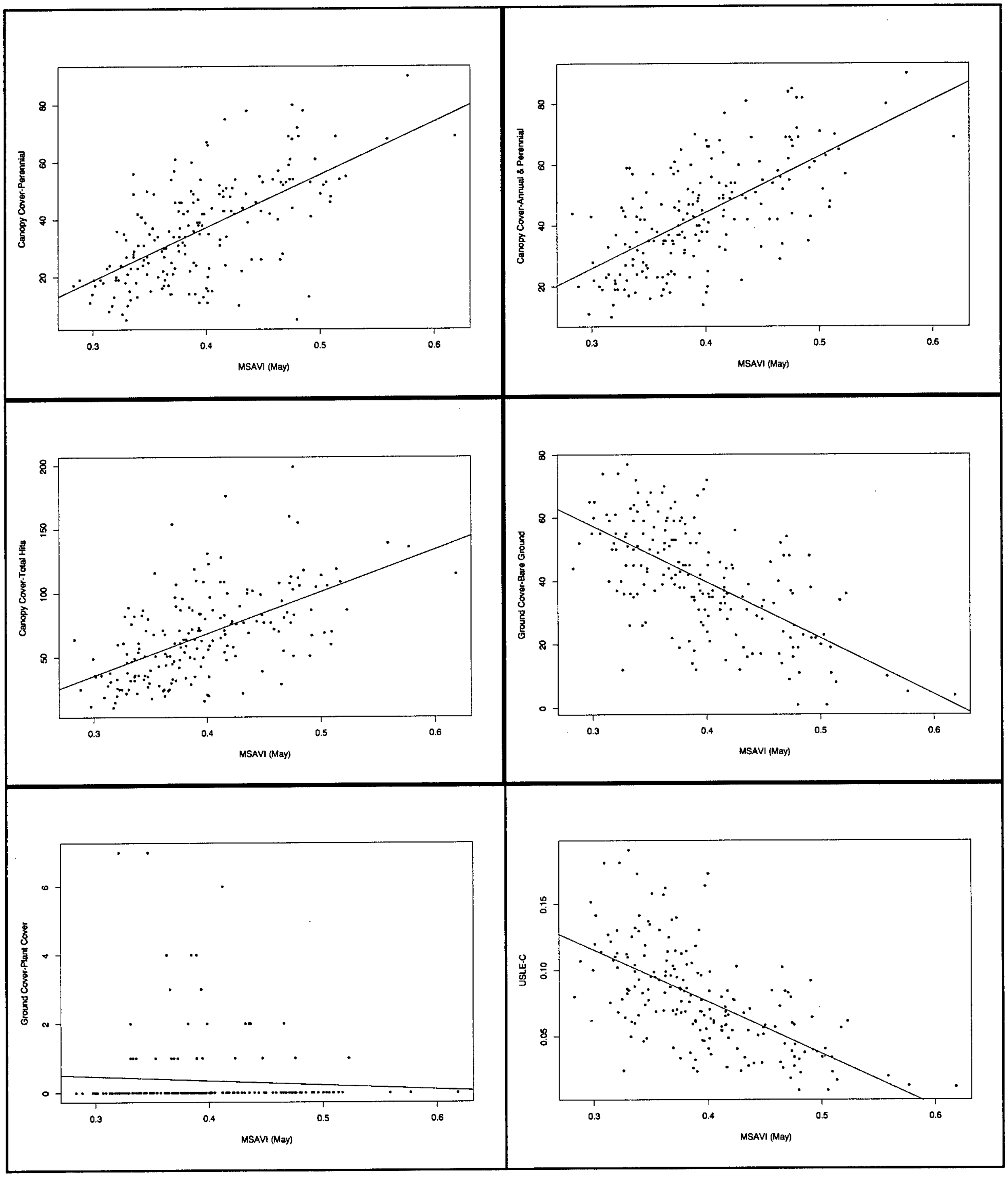


**Figure 4. Scatter diagrams and regression lines showing the relationship between the May MSVI and selected LCTA field measures.**

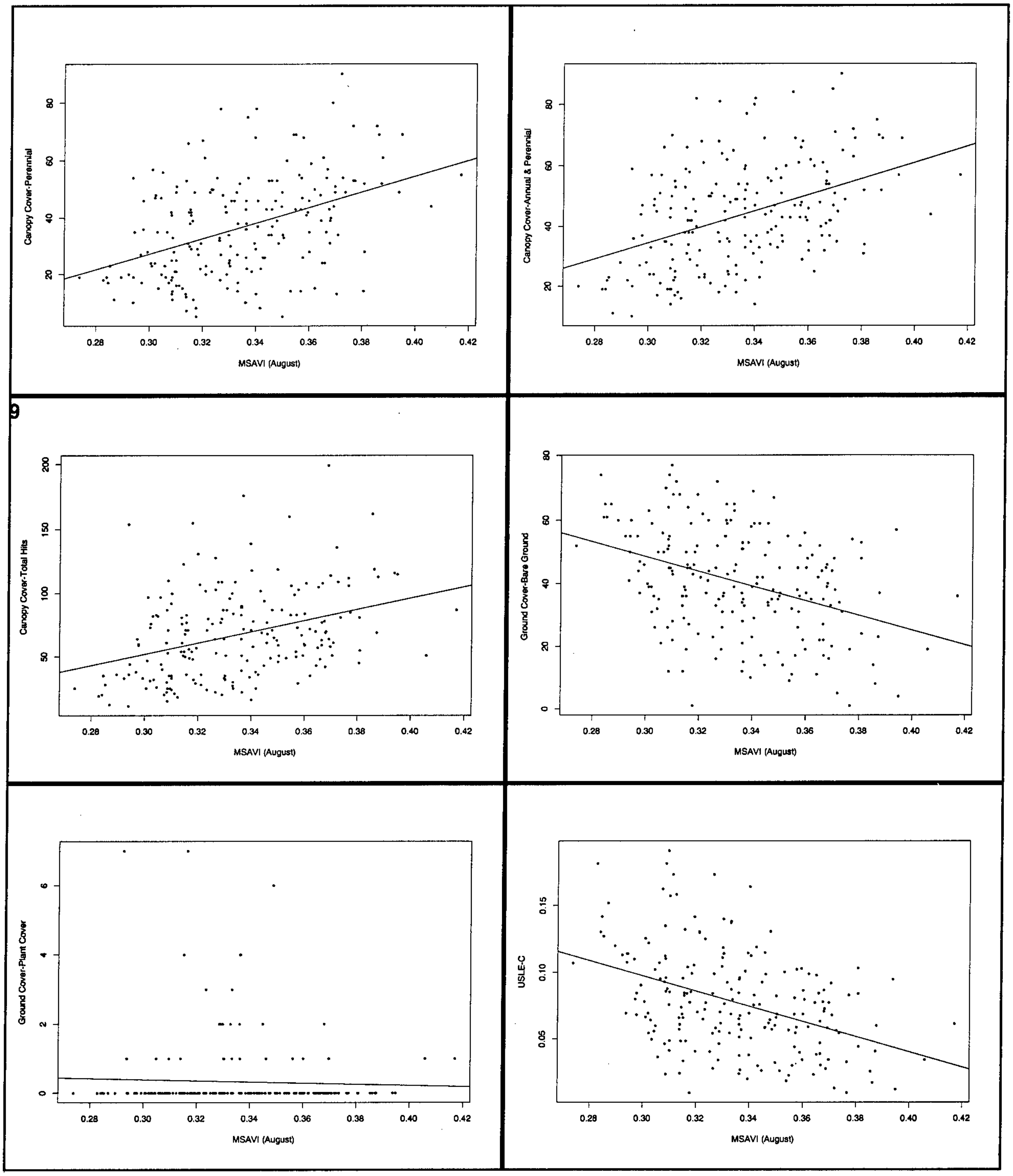


**Figure 5. Scatter diagrams and regression lines showing the relationship between the August MSVI and selected LCTA field measures.**

were also fit using BG and USLE-C measures for the dependent variable. These variables were used because they also had strong linear correlations with MSAVI. Coefficients of determination for the regression were 0.40 and 0.38 for BG and USLE-C, respectively. Residual errors for the regressions were 13.12 and 0.03 for BG and USLE-C, respectively.

# 7 Conclusions and Recommendations

## Linear Relationship

One objective of this study was to determine if a linear relationship exists between LCTA cover measures and satellite-imagery-derived vegetation indices. This objective was accomplished by examining different LCTA-data-derived cover measures, different vegetation indexes, and different imagery dates within the field data collection period. Correlation analysis was used to determine if a linear relationship could be found.

Visual inspection of the bivariate scatter plots of cover values and vegetation index values indicates existence of some linear relationship. The Pearson Product Moment correlation measures were strong for several of the cover measures and vegetation indices derived from the May image, also supporting the conclusion that a linear relationship exists. Correlation measures for the cover measures and the vegetation indices derived from the August satellite data also indicate a weak linear correlation.

Differences between correlation coefficients for particular cover variables and the various indices were shown to be small. In general, MSAVI exhibited the strongest correlations with the range of LCTA cover variables tested. Other indices did not consistently exhibit strong correlations with the same set of LCTA variables. Because the MSAVI consistently showed a strong correlation, its use is recommended in subsequent study of the correlation of LCTA cover values and vegetation indices.

Note that the PD54 vegetation index was not used in the correlation study because of the inability to identify a defensible soil line. It may be possible to identify a maximum vegetation line and take the perpendicular distance from it rather than the soil line. Topographic normalization of the image was shown to have a minimal effect on the linear relationship between cover and vegetation index in this study.

The LCTA cover measure derived from the canopy cover CCTOT showed the strongest correlation with the MSAVI. Both the BG and the USLE-C cover measures also had a strong correlation with the MSAVI. However, the scatter plot for the combination of USLE-C and MSAVI may be somewhat curvilinear. A log transformation of the USLE-C values may provide a more linear relationship. However encouraging the results of the correlation may be, the *r* values from the Pearson Product Moment correlation and inspection of the scatter plots indicate the overall strength of the linear relationships are much lower than in similar studies.

Of the two image dates examined in this study, the May image had a much stronger correlation with the cover measures than did the August image. The strength of relationship might be further improved by a more optimum image date. A more optimum date for imagery than those used in this study may exist to estimate a cover measure derived from LCTA data. However, the date would certainly change from year to year because of varying phenology. Different types of vegetation or the same type of vegetation at different phenological states may yield somewhat different spectral responses. The use of a cover measure based on plant type may prove useful also.

## Improved Vegetative Cover Maps

While research was conducted for this report, vegetative cover maps of YTC were improved and updated for ongoing carrying capacity and erosion modeling efforts. Results of this research demonstrated a relatively high correlation between field measurement CCTOT and MSAVI. Based on the linear regression formula between these two variables, CCTOT was calculated for each individual pixel or data element in the Thematic Mapper image of YTC. Extrapolation of CCTOT estimates based on this linear relationship has provided a more accurate map of vegetative cover than what previously existed for YTC.

## Conclusions

The strength of correlation between vegetation indices derived from imagery and corresponding LCTA field measurements also may have been affected somewhat by the characteristics of the data sets that were analyzed. As suggested in previous literature, relatively strong correlations between vegetation indices and field measurements have been established. However, many of these studies have been conducted within a stringent experimental design in which field measurements were collected specifically for the respective research projects and, therefore, many of the problems associated with an existing inventory and monitoring program are alleviated. Field sampling is usually conducted in close proximity to the image acquisition date, and field sampling and methodologies are usually selected that are best suited for integration and interpretation of raster-based satellite imagery. LCTA field data is collected throughout the growing season for the purpose of assessing trends in land condition over larger areas and over several years.

Not only are the field collection dates of the individual plots widely dispersed around the image acquisition date, but point intercept data are collected along a 100-m line transect that crosses over several pixels of an image. Potential inaccuracies exist in the spatial location of each data source, and these inaccuracies may, in turn, affect the strength of correlation measured between imagery and ground variables. In this study, satellite imagery was georeferenced with an overall accuracy of +/- 15 m. LCTA transects were located at an accuracy level of +/- 5 m. Although these accuracies are generally acceptable for geospatial analysis of natural resources, it may still be possible that the pixels from the index imagery did not correspond to the locations of some transects on the ground. However, because of the way in which LCTA plots are initially allocated in the field, they should be inside relatively homogenous areas in terms of vegetation cover and, therefore, these spatial inaccuracies should have only a very minimal effect on the strength of correlations between the image and ground variables.

In addition to potential errors introduced by spatial inaccuracies, the standard information collected along LCTA transects may not always be the best representation of cover for the area as imaged by the satellite. For example, when a single value for variable CCTOT was used to calculate the correlation measure, that value was assumed to represent the total canopy cover for the entire areas imaged by 3 to 5 pixels of imagery. In some cases, canopy cover may have varied from one end of the transect to the other, but a single value was used to calculate the correlation. A different field sampling design (i.e., quadrat samples that correspond more to the size of raster pixels in the imagery) may provide more representative measures of what is imaged by the sensor. It is possible that CCTOT may underestimate the amount of vegetative cover along a transect, while TOTHIT may actually overestimate the amount of vegetative cover. An average value for all measurements recorded along a transect may also provide a more representative measure, which could be used to measure the correlation between the vegetation index and cover.

The results of this study are encouraging and the techniques described provide an improved method for estimating the quantity of vegetative cover across large and complex rangelands with satellite imagery and LCTA cover data. This study also identified several data acquisition and processing issues that warrant further investigation. Studies are under way to assess the importance of coordinating and timing field data collection and image acquisition dates as a means of improving the strength of the relationships between image and LCTA ground-truth data.

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