Evaluation of Single-Band-Video and Video-Band-Based Indices for Grassland Phytomass Assessment

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ABSTRACT: Single-band-video and video-band-based vegetation indices (composite images) were evaluated for their potential to assess phytomass production within grass plots that were fertilized with five rates of nitrogen. Eleven single-band images were acquired by equipping four black-and-white video cameras [three of them visible (0.40 to 0.70 μm) and one visible/infrared (IR) (0.40 to 1.1 μm) sensitive] with visible and IR narrowband filters. Thirteen vegetation indices were produced on an image processor from the various single-band (composites) images: green/red, IR/blue, IR/green, IR/yellow-green, IR/yellow, IR/orange, IR/orange-red, IR/dark orange-red, IR/red, IR/dark red, IR/deep dark red, normalized difference vegetation index (NDVI), and transformed vegetation index (TVI). Digital data were obtained from the 24 images and regressed on amounts of phytomass. Coefficients of determination (r^2) from four single band images (orange-red, red, dark red, and IR) were significant. Moreover, r^2 values calculated from twelve of the indices were significant (all at $p = 0.01$). The only nonsignificant r^2 coefficient was obtained from regressing TVI digital data on amount of phytomass. Although the significant r^2 coefficients obtained from the indices varied, a qualitative evaluation of the various composite images showed them to be similar for separating among the fertilizer treatments. These results indicate both single-band-video and video-vegetation-indices will be useful to assess the amount of grass phytomass production.

INTRODUCTION

Spectral variables, including both single band and band transformations have been used extensively in the remote sensing field to monitor the physiological status of vegetation (Tucker, 1979; Carneggie *et al.*, 1983). Examples of transformations are vegetation indices where ratio-based transformed data sets are related to vegetation parameters. Common vegetation indices include the green/red ratio (Kanemasu, 1974), infrared (IR)/red ratio (Colwell, 1974; Tucker, 1979), the normalized difference vegetation index (NDVI = IR-red/IR + red) and transformed vegetation index (TVI = $\sqrt{(\text{IR-red})/(\text{IR}+\text{red}) + .5}$) (Rouse *et al.*, 1973, 1974). Several researchers have used single bands and vegetation indices derived from both reflectance data and Landsat image analysis to estimate or assess crop growth and to monitor development and phytomass production on rangelands (Kanemasu, 1974; Carneggie and DeGloria, 1974; Deering *et al.*, 1975; Maxwell, 1976; Tucker, 1979; Richardson *et al.*, 1983; Pinter *et al.*, 1985; Jackson and Pinter, 1986).

Recently, video imaging systems have been developed into remote sensing tools and have been proven useful for vegetation assessment (Edwards, 1982; Vlcek, 1983; Meisner and Lindstrom, 1985; Nixon *et al.*, 1985; Vlcek and King, 1985; Everitt and Nixon, 1985; Nixon *et al.*, 1987). Video data's electronic format makes it compatible with computer image processing techniques, thus allowing applications derived from Landsat-type computer processing of the data (Meisner, 1986). Moreover, video cameras have higher light sensitivity than do film cameras, and this permits imaging within narrow spectral bands. Thus, objects can be viewed through narrowband interference filters across a wide spectral range (0.4 to 2.0 μm) (Nixon *et al.*, 1985; Everitt *et al.*, 1987a). Everitt *et al.* (1986) used red, IR, and IR/red ratio video data for the assessment of phytomass levels in grass plots and found that the IR/red ratio enhanced the viewer's ability to note more differences among phytomass levels than did single-band images. More recently Lulla *et al.* (1987) used video data in the form of three common vegetation indices (IR/red, IR/green, and IR-red/IR + red) to discriminate successfully among vegetation types in a rangeland environment. No other information is presently available on the evaluation of video-band-based vegetation indices for assessment of vegetation parameters. Our objective in this study was to evaluate the potential use of various multispectral narrowband video images and video-band-based vegetation indices to discriminate among the phytomass production of grass land field plots with a range of phytomass levels.

MATERIALS AND METHODS

The experimental site was a 1.1-ha pasture located at the Texas A&M University, Hoblitzelle Ranch near Mercedes, Texas. The soils and dominant grasses on the site have been described by Everitt *et al.* (1986). A randomized complete block design was used with four replications of five fertilizer treatments: 0, 56, 112, 168, and 224 kg of elemental nitrogen(N)/ha which were applied by broadcasting ammonium nitrate (NH_4CO_3) on 4 March 1985. The area received adequate rain following fertilization, and the grass was growing actively by mid-April when data were collected.

Imagery of the experimental site was taken with four black-and-white Sony* AVC-3450 video cameras, each with a Sony SLO-340 video cassette recorder (0.5-in. Beta format) (Nixon *et al.*, 1985). One of the cameras was modified with an RCA Ultricon (TM) 4875/U camera tube (0.7 in.) to give visible/near-infrared light (0.30 to 1.1 μm) sensitivity. The other three cameras had visible light (0.4 to 0.70 μm) sensitivity only. Imagery was obtained with 11 narrowband filters (Table 1). The infrared (IR) (0.815 to 0.827-μm) and deep dark red (0.712 to 0.725-μm) narrowband filters were used with the visible/near-infrared sensitive camera, whereas the other nine filters were used with the visible sensitive cameras. The camera's lens focal length was 50 mm. Imagery of the study site was taken on 15 April 1985, six weeks after fertilization. All imagery was obtained at a 900-m altitude using a Cessna 182 airplane. To obtain imagery with

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TABLE 1. NARROWBAND FILTERS USED ON VIDEO CAMERAS

Filter	Sensitive Waveband (μm)
Blue	0.467 - 0.473
Green	0.516 - 0.524
Yellow-green	0.543 - 0.552
Yellow	0.573 - 0.583
Orange	0.586 - 0.595
Orange-red	0.614 - 0.625
Dark orange-red	0.633 - 0.645
Red	0.644 - 0.656
Dark red	0.656 - 0.668
Deep dark red	0.712 - 0.725
Infrared	0.815 - 0.827

the 11 filters, multiple passes were made over the plots between 1200 and 1300 hours under sunny conditions.

Herbaceous phytomass measurements were made concurrent with imagery collection. They were made by clipping vegetation at ground level within four, 50-by-50-cm quadrants within each plot. Phytomass samples were oven-dried for 72 hours at 65°C. For statistical analyses, the four measurements within each plot were averaged.

The video scene for each narrowband filter image (Table 1) was entered digitally into an I²S image processor using a casette recorder that was interfaced to the image processor's video digitizer through an Edutron time-base corrector. The digitized images were stored on a computer disk and backed up on magnetic tape to avoid loss of data. The image processor was also used to warp the 11 narrowband video scenes to a common geometric base by using the red narrowband image as the base. Thirteen indices were obtained with the 11 narrowband images (Table 2). The 11 simple indices (i.e., IR/red) were directly processed with the I²S software's divide function to produce video composite images. The NDVI and TVI indices were obtained by using the addition-subtraction and division functions of the image processor and a computer program, respectively. Many of the indices used here have been reported on previously by other researchers (Kanemasu, 1974; Rouse *et al.*, 1973, 1974; Tucker, 1979). Because of the large number of narrowband filters available, however, several new indices were evaluated (i.e., IR/blue, IR/yellow, IR/dark red) to determine their potential for assessing phytomass production. The image processor's Train and Prepare Functions were used with the 11 narrowband images and 13 composite images to acquire digital data from each whole plot. The video images shown here were photographed from the image display monitor.

Digital video data were regressed on grass phytomass yield measurements (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The regression equations and coefficients of determination (r^2) obtained by regressing digital data from the 11 single-band video images on phytomass are given in Table 2. Only the r^2 coefficients obtained by regressing orange-red, red, dark red, and IR digital data on phytomass were significant statistically. Digital data from the three visible bands were inversely related to phytomass, whereas that obtained from the IR band was directly related to phytomass.

A qualitative evaluation of the various single-band images generally concurred with the quantified data. Everitt *et al.* (1986) have previously described the red and IR images and showed that generally three phytomass levels could be seen within the plots. Similar differences could be seen within the orange-red and dark red images of the plots (imagery not shown). The nonfertilized plots could be readily distinguished from the more productive N-fertilized plots (56, 112, 168, and 224 kg N/ha), while plots that received 56 kg N/ha were generally distinguishable from plots that received 112, 168, and 224 kg N/ha. However, plots that received the three highest N levels could not be visually differentiated.

The regression equations and r^2 coefficients obtained by regressing the digital data from the thirteen video-band-based indices on phytomass are given in Table 3. Twelve of the r^2 coefficients were highly significant ($p=0.01$), and digital data from all indices were directly related to phytomass. Only the r^2 coefficient for the TVI indice was not significant. Possibly subjecting the video data through the TVI's mathematical formula subdued differences among the treatments. Apparently, ratioing the various video bands, or subjecting them to addition-subtraction functions and then ratioing, normalized the effects of soil background reflectance variations and greatly enhanced differences among treatments. Our results agree with those of previous researchers using indices to evaluate reflectance data and Landsat and film image analysis to estimate vegetation vigor (Colwell, 1974; Kanemasu, 1974; Deering *et al.*, 1975; Tucker, 1979; Richardson *et al.*, 1983; Everitt *et al.*, 1987b).

Figures 1A through 1F portray green/red, IR/orange-red, IR/deep dark red, NDVI, and TVI composite images, and the plot diagram, respectively, of the fertilized grass plots. Within the green/red image (Figure 1A) control plots (1) had a dark gray image tone that was distinguishable from the lighter gray im-

TABLE 2. REGRESSION EQUATIONS AND COEFFICIENTS OF DETERMINATION (r^2) OF DIGITAL COUNT DATA FROM 11 SINGLE-BAND VIDEO SCENES OF THE GRASS PLOTS ON PHYTOMASS (KG/HA).

Dependent Variable	Independent Variable	Equation	r^2
Phytomass	blue digital	$y = -5172.2 + 520440/x$	0.41 N.S.
"	green "	$y = -3795.0 + 763420/x$	0.29 N.S.
"	yellow-green "	$y = -6455.8 + 1410300/x$	0.40 N.S.
"	yellow "	$y = -1556.8 + 553530/x$	0.35 N.S.
"	orange "	$y = -3764.6 + 879530/x$	0.43 N.S.
"	orange-red "	$y = -5301.0 + 1093000/x$	0.61 *
"	dark orange-red "	$y = -1331.9 + 410110/x$	0.45 N.S.
"	red "	$y = -3567.6 + 782500/x$	0.58 *
"	dark-red "	$y = -3828.2 + 667850/x$	0.70 **
"	deep dark red "	$y = -6924.0 + 1080200/x$	0.39 N.S.
"	IR "	$y = -4712.6 + 58.0x$	0.67 **

**Significant at 0.01 probability level.
*Significant at 0.05 probability level.
N.S. = not significant

TABLE 3. REGRESSION EQUATIONS AND COEFFICIENTS OF DETERMINATION (r^2) OF DIGITAL COUNT DATA FROM 13 VIDEO INDICE COMPOSITE SCENES OF THE GRASS PLOTS ON PHYTOMASS (KG/HA).

Dependent Variable	Independent Variable	Equation	r^2
Phytomass	green/red digital	$y = 13918.0 + 436.93x$	0.77**
"	IR/blue "	$y = -3538.5 + 70.136x$	0.80**
"	IR/green "	$y = -3021.2 + 125.89x$	0.73**
"	IR/yellow-green "	$y = -3072.1 + 195.48x$	0.74**
"	IR/yellow "	$y = -1251.4 + 112.54x$	0.64**
"	IR/orange "	$y = -2332.8 + 122.96x$	0.74**
"	IR/orange-red "	$y = -2535.3 + 30.419x$	0.79**
"	IR/dark orange red "	$y = -1237.2 + 26.974x$	0.71**
"	IR/red "	$y = 636.75 + 18.905x$	0.72**
"	IR/dark red "	$y = -2096.2 + 30.297x$	0.85**
"	IR/deep dark red "	$y = -4332.0 + 146.31x$	0.88**
"	NDVI IR-red/IR+red "	$y = -4031.0 + 243.76x$	0.63**
"	TVI $\sqrt{(\text{IR-red})/(\text{IR+red}) + .5}$	$y = 14281.0 + 83.85x$	0.51N.S.

**Significant at 0.01 probability level.
N.S. = Not significant.

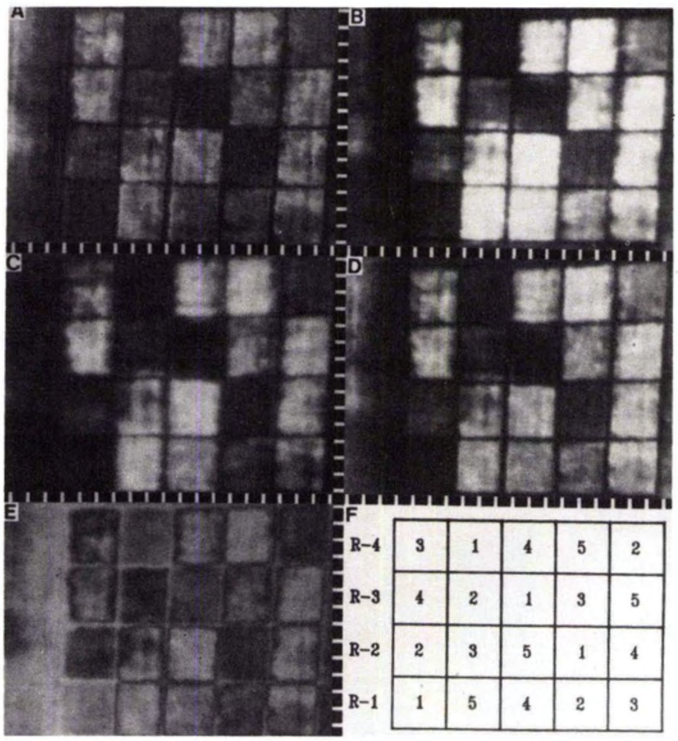

FIG. 1. Green/red (A), IR/orange-red (B), IR/deep dark red (C), NDVI (D), and TVI (E) composite images and plot diagram (F) of grass plots with different levels of nitrogen fertilizer. Treatments: (1) nonfertilized; (2) 56 kg N/ha; (3) 112 kg N/ha; (4) 168 kg N/ha; (5) 224 kg N/ha.

ages of the N-fertilized plots (2, 3, 4, and 5). Plots that received 56 kg N/ha (2) were generally distinguishable from plots that received 112, 168, and 224 kg N/ha (3, 4, and 5, respectively). Differences in image tones among the plots that received the three higher N levels were more subtle, but within most blocks the 224 kg N/ha treatment plots gave a more uniform whitish-gray image that was separable from plots that received 112 and 168 kg N/ha.

The IR/orange-red, IR/deep dark red, and NDVI composite images (Figures 1B, 1C, and 1D, respectively) were very similar. Differences among the various treatments in the IR/orange-red, IR/deep dark red, and NDVI images were comparable to those in the green/red image, except that the N fertilized plots had a more pronounced whitish-gray response in these three scenes. This was attributed to the high reflectivity within the IR band. Figure 1E shows the TVI composite image of the plots. Although the r^2 obtained from regressing the TVI digital data on phytomass was not significant statistically, the image is shown here. More variability can be seen among the various treatments within the TVI image than in the other composite images. However, plots receiving the two highest N levels (224 and 168 kg N/ha) generally can be separated from each other and from the other treatment plots.

CONCLUSIONS

Both single-band and video-band-based vegetation indices can be used to assess or estimate the amount of grass phytomass production, but the video-band indices were superior to single-band images. Numerous vegetation indices (e.g., green/red, IR/blue, IR/orange-red, IR/dark red, NDVI) were used successfully to discriminate among grass plots with variable amount of phytomass, but no index was superior to another, excluding the TVI. The large number of narrowband filters available for various wavebands makes video a valuable remote sensing tool because the multispectral images can be subjected to computer image processing techniques to produce numerous vegetation indices and digital data can be obtained form these various band combinations. These findings should be useful to range resource managers interested in using remote sensing techniques to assess comparisons of phytomass production on rangelands.

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