Light reflectance characteristics and video remote sensing of pricklypear

J.H. EVERITT, D.E. ESCOBAR, M.A. ALANIZ, AND M.R. DAVIS

Abstract

This paper describes the use of a black-and-white visible-infrared (0.4–2.4 μm) sensitive video camera, filtered to record radiation in the 1.45–2.0 μm mid-infrared (MIR) spectral region, for distinguishing the succulent plant species pricklypear (*Opuntia lindheimeri* Engelm.) on rangelands in southern Texas. Ground-based spectroradiometric plant canopy measurements at 5 sampling dates revealed that pricklypear had significantly lower ($p = 0.05$) reflectance than that of associated plant species and soil over the 1.50–1.75 μm MIR water absorption spectral region. Airborne MIR video imagery of rangeland areas indicated that pricklypear populations could be differentiated from other landscape features. The optimum time for distinguishing the evergreen pricklypear was in January–February because most of the associated woody plant species were deciduous and lost their foliage during this period. Computer-based image analyses of MIR video imagery showed that pricklypear populations could be quantified, indicating that MIR video imagery may be useful for distinguishing and mapping pricklypear populations over large and inaccessible rangeland areas.

Key Words: video remote sensing, spectral characteristics, range management, *Opuntia*

Pricklypear (*Opuntia lindheimeri* Engelm.) is a succulent shrub 1–3 m high found on rangelands of south and west Texas and northeastern Mexico (Correll and Johnston 1970). It is often a troublesome species that forms dense stands up to 10 m across. Pricklypear is especially troublesome on poor condition or sparsely covered grasslands where it spreads rapidly because the cladophylls (pads) or branches and seed that have passed through birds and animals can readily become established on bare ground (Smith and Rechenthin 1964). It is difficult to control by mechanical means, especially root plowing, because this method breaks up and spreads the cladophylls, which often drastically increase the stand density. Broadcast sprays or granular herbicides offer the most promising control methods for pricklypear (Scifres 1980).

Although pricklypear can create a serious brush problem on rangeland, it is a beneficial plant to wildlife and livestock. Pricklypear provides protection for quail and other birds (Scifres 1980, Lehmann 1984), and the fruit and cladophylls are eaten by several species of birds and animals (Vines 1960, Arnold and Drawe 1979, Everitt et al. 1981a, Lehmann 1984). It is also browsed by cattle (Everitt et al. 1981b) and is often used as an emergency feed in drought times or winter after burning off the spines (Smith and Rechenthin 1964, Scifres 1980). Pricklypear is not inherently nutritious, but Gonzalez (1989) recently reported that N and P fertilization can be used to increase the nutritive value and productivity of pricklypear.

Water in plant leaves is a strong absorber of infrared light particularly over the 1.35 to 2.5 μm middle-infrared (MIR) water absorption region of the electromagnetic spectrum (Gates et al. 1965, Knipling 1970). Visible, near-infrared (NIR), and MIR reflectance measurements revealed that the MIR water absorption region was best for distinguishing between succulent and nonsucculent plant species (Gausman et al. 1977, 1978; Everitt et al. 1986c). This is a spectral region that photographic film (black-and-white and color-infrared) is not sensitive to because its sensitivity terminates at the 0.90 μm wavelength. Everitt et al. (1987) reported that a black-and-white video camera with MIR (1.45 to 2.0 μm) sensitivity could be used as a remote sensing tool to distinguish the succulent crop plant species onions (*Allium cepum* L.) and aloe vera (*Aloe barbadensis* Mill.) from nonsucculent crop plant species. The objective of this study was to determine the feasibility of

Authors are range scientist, remote sensing specialist, biological technician, and airplane pilot, respectively, ARS-USDA, 2413 E. Hwy 83, Weslaco, Texas 78596.

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using airborne MIR video imagery to distinguish pricklypear on south Texas rangelands. The ability to remotely distinguish pricklypear over large and inaccessible rangeland areas would be beneficial to range managers and wildlife ecologists. This information would be beneficial to range managers to monitor the spread or contraction of pricklypear over time, delineate areas needing control, and for mapping areas of reserve livestock forage during drought. Wildlife managers would benefit by having the capability to map areas of wildlife habitat.

Materials and Methods

This study was conducted in rangeland areas of south Texas. Study sites were located near Alice, Campbellton, Edinburg, Mercedes, and Weslaco in the Rio Grande Plain resource area (Gould 1975). Ground reflectance measurements, aerial video imagery, and ground truth data were conducted for this study. Ground truth observations were made to verify video imagery, whereas reflectance measurements were made to interpret the imagery. Video imagery and reflectance measurements were obtained of pricklypear infested rangelands at different dates during the growing season to determine the optimum time of year to distinguish pricklypear from associated plant canopies.

Reflectance measurements were made near Weslaco, Texas, using a large truck-based Exotech[1] spectroradiometer (Leamer et al. 1973) in August and November 1989 and January, February, and May 1990. Reflectance measurements were made on pricklypear, huisache [*Acacia farnesiana* (L.) Willd.], honey mesquite (*Prosopis glandulosa* Torr.), mixed herbaceous species, and bare soil. Huisache and honey mesquite are woody plant species that often occur in association with pricklypear, whereas the dominant herbaceous species are usually comprised of mixtures. Major herbaceous species were buffelgrass (*Cenchrus ciliaris* L.), sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray], hooded windmillgrass (*Chloris cucullata* Bisch.), common bermudagrass [*Cynodon dactylon* (L.) Pers.], and western ragweed (*Ambrosia psilostachya* DC). Measurements were not made on huisache and honey mesquite in January and February because they are deciduous species that lose their leaves in winter. Reflected radiation was measured on each of 7 randomly selected plant canopies (each species or mixture) or soil surfaces on each date at 0.05 μm increments over the 0.45 to 2.45μm spectral region with a sensor that had a 15-degree field-of-view placed approximately 3.0 m above each target. The sensor was mounted on a Truco aerial lift ("cherry picker"). Measurements were made under sunny conditions between 1100 and 1500 hr. Overhead conventional color photographs were taken 2–3 m above canopies of the various species and mixtures of species to help interpret canopy reflectance data.

The video equipment consisted of 1 MII 2500 video camera, 2 Cohu 4810 video cameras, and 3 Panasonic AG-7400 Super-VHS portable video cassette recorders (1/2-inch format, 400 horizontal line resolution). The MII camera had a specially designed lead oxide (PbO)—lead sulfide (PbS) camera tube (1.0-inch format) to give visible-infrared light (0.4–2.4 μm) sensitivity. A filter combination of 2 long wavepass filters allowing transmittance of light from the 1.45–2.0 μm were used on the MII camera (Everitt et al. 1986a), giving it sensitivity in the MIR water absorption region. The Cohu cameras had charge coupled device (CCD) image sensors (0.7-inch format) with visible/NIR (0.4–1.1 μm) sensitivity. One of the Cohu cameras was equipped with a NIR (0.815–0.827 μm) narrowband filter plus a 0.5 neutral density filter. The second Cohu camera was equipped with a red (0.644–0.656 μm) narrowband filter. All cameras had Canon zoom lenses which were set at 40-mm focal lengths. Differences in lens optics, sensor types and format between the MIR tube camera and the red and NIR CCD cameras caused the imagery to have slightly different fields-of-view.

Video recordings were obtained near Alice, Campbellton, Edinburg, and Mercedes, Texas. Imagery was acquired near Alice and Campbellton in August and November 1989 and January and February 1990, and near Edinburg and Mercedes in May, June, August, and October 1989. Additional imagery was taken near Edinburg in January 1990. Although the imagery dates did not all coincide with the ground reflectance measurement dates, imagery was generally obtained of the plant species during the same phenological stages and vegetative conditions that the plants were in when reflectance measurements were made. Simultaneous recordings of each area were taken using all 3 video cameras. Imagery was obtained at altitudes ranging from 600–1,200 m. All imagery was obtained with a Cessna 206 airplane with the video cameras mounted vertically in the floor. A characteristic of the MIR sensitive camera was persistence of image (image lag) which caused blurring when the camera was moving. This was attributed to its PbO-PbS tube and was more apparent at lower altitudes (600–900 m). To compensate for this the pilot slowed the plane to approximately 70 knots.

Ground-level video recordings were also obtained of pricklypear with the red, NIR, and MIR filtered video cameras to illustrate its spectral light characteristics in each band.

Ground truth data were collected at the study sites at or near the time imagery was obtained. Data were recorded relative to plant species, plant height, density, cover, soil type, and soil surface conditions. Conventional color ground photographs were also obtained at each site.

Middle-infrared video scenes of pricklypear acquired at an altitude of 1,050 m were converted to digital format (512 $\times$ 512 pixel format; digitized ground pixel size of 0.66 m) with an image processing system that consisted of a PC-AT clone computer having a Matrox MVP/AT board and IMAGE-PRO II processing software. Images were subjected to the "index replacement" function which permitted the training of pixels that represented pricklypear in the scenes. This technique permitted the computer to produce a classified binary image that highlighted pricklypear as white pixels and everything else in the image as black pixels. The IMAGE-PRO II "analysis" functions were used to determine the percentage of pricklypear in each image. Video images shown here were photographed from an image display monitor.

A manual photointerpretive procedure was used on a print of 1 of the digitized MIR scenes of pricklypear to compare differences in classification (Everitt et al. 1988, 1991). A map was made of the print by tracing areas where pricklypear was thought to occur onto a transparent paper overlay of the print. Areas where pricklypear was thought to occur were coded black and the remainder of the map was left white. The tracing was digitized and subjected to the "index replacement" and IMAGE-PRO II "analysis" functions as described above to obtain the percentage of pricklypear in the image.

Plant canopy cover was determined on 3–4 canopies of each plant species or mixture on each date that reflectance measurements were made to help interpret the spectral data. Canopy cover was obtained from the overhead photographs taken of the canopies by subjecting them to a grid technique. This consisted of digitizing a color slide transparency of each canopy and superimposing a grid over it on the image display monitor. Percent cover was calculated from the number of squares occupied by plant tissue. The computer grid was utilized since it was available with the image processing software. Water content was also determined on the different plants at the time of reflectance measurements by collecting 10 leaf/cladophyll samples from each species or mix-

[1]Mention of a company name or trademark is for the reader's benefit and does not constitute endorsement of a particular product by the U.S. Dept. of Agriculture over any others that may be commercially available.

tures. Each sample was a composite from 3 plants. Leaves/cladophylls were enclosed in plastic bags, stored on ice to minimize dehydration, and transferred to the laboratory for measurements. Pricklypear cladophylls were cut into strips before measuring water content to help expedite the drying process. Percent water content are reported on an oven dry weight basis (68° C for 72 h).

Reflectance data were calculated from the wavelengths that most closely corresponded to the filters used to acquire the video images. These included the 0.65 μm for the visible red, the 0.80 and 0.85 μm for the NIR, and the 1.50, 1.55, 1.60, 1.65, 1.70, and 1.75 μm for the MIR water absorption region. The mean reflectances were computed for the 0.80 and 0.85 μm and 1.50, 1.55, 1.60, 1.65, 1.70, and 1.75 ρm wavelengths to represent the NIR and MIR spectral regions, respectively. Duncan's multiple range test was used to test the statistical significance at the 0.05 probability level among means (Steel and Torrie 1980).

Results and Discussion

Light reflectance values of pricklypear, 2 associated plant species, mixed herbaceous species, and soil within 3 wavelength intervals for 5 sampling dates are given in Table 1. In August and November 1989, the visible (0.65 μm) and NIR (0.80–0.85 μm) reflectance values of pricklypear did not differ from that of several associated plant species. The inability to separate pricklypear from associated species at the visible wavelength was attributed to similar foliage colors among the species (Myers et al. 1983). Pricklypear had a gray-green to green color that was comparable to that of mixed herbaceous species on both dates and to that of the associated species in November. At the NIR (0.80–0.85 μm) wavelength pricklypear had a reflectance value similar to bare soil in August, and similar to honey mesquite in November.

Table 1. Mean light reflectance measurements of pricklypear, honey mesquite, huisache, mixed herbaceous species, and soil for the visible, near-infrared, and mid-infrared wavelength intervals. Measurements were made on 5 dates for bare soil, mixed herbaceous species and pricklypear. Honey mesquite and huisache are deciduous species and were not available for measurements in January and February 1990. Reflectance measurements were made near Weslaco, Texas.

Date	Plants and soil	Reflectance values[a] Wavelengths, μm 0.65	0.80–0.85	1.50–1.75
August 1989	Bare soil (crusted)	15.0 a	24.2 bc	39.3 a
	Honey mesquite	2.3 d	31.5 a	11.5 d
	Huisache	3.3 c	31.5 a	15.5 c
	Mixed herbaceous species	6.4 b	21.7 c	23.7 b
	Pricklypear	5.9 b	25.5 b	8.4 e
November 1989	Bare soil	13.1 a	18.8 d	33.6 a
	Honey mesquite	3.0 c	25.3 ab	11.8 d
	Huisache	4.3 c	23.2 bc	16.1 c
	Mixed herbaceous species	6.9 b	20.1 cd	27.3 b
	Pricklypear	5.5 bc	27.2 a	8.9 e
January 1990	Bare soil	10.9 a	19.8 b	35.9 a
	Mixed herbaceous species	7.0 b	20.9 b	30.1b
	Pricklypear	6.1 c	23.3 a	7.3 c
February 1990	Bare soil	10.7 a	18.5 c	32.1 a
	Dormant herbaceous species	10.7 a	17.7 c	27.7 b
	Mixed herbaceous species (green)	5.8 b	27.2 a	25.9 b
	Pricklypear	5.9 b	23.0 b	7.5 c
May 1990	Bare soil (crusted)	18.4 a	28.8 ab	43.7 a
	Honey mesquite	2.5 d	30.9 a	12.1 c
	Huisache	3.1 cd	26.4 bc	13.7 c
	Mixed herbaceous species	6.7 b	25.2 cd	24.1 b
	Pricklypear	4.5 c	22.8 d	5.9 d

[a]Values within columns at each date of sampling followed by the same letter do not differ significantly at the 0.05% probability level according to Duncan's multiple range test.

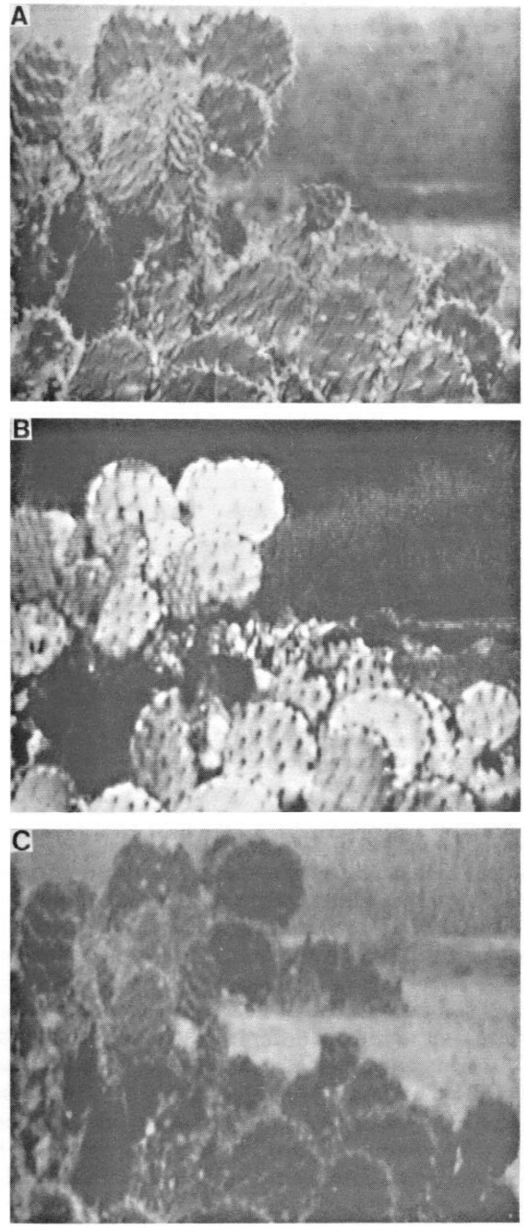

Fig. 1. Red (A), near-infrared (B), and mid-infrared (C) ground video images of pricklypear in a rangeland area near Weslaco, Texas.

In vegetation, NIR reflectance is highly correlated with plant density (Myers and Allen 1968, Wiegand et al. 1974, Everitt et al. 1986b). Phytomass measurements were not made, but plant cover data (Table 2) indicated that pricklypear cover was similar to that of both honey mesquite and huisache in November. This parameter probably contributed to the similarity of reflectance values on that date. Mean reflectance measurements over the 1.50–1.75 μm (Table 1) MIR water absorption spectral region in August and November showed that pricklypear had significantly lower reflectance than all other canopy conditions on both dates. The lower MIR reflectance values of pricklypear were attributed to its higher water content (Table 2) than that of the other plant species which

Table 2. Mean leaf or cladophyll water content and canopy cover of pricklypear and associated plant species on 5 dates.

Date	Plant species or mixture	Water content (%)	Canopy cover (%)
August 1989	Honey mesquite	58.1 ± 1.2[a]	91 ± 2.5
	Huisache	58.5 ± 1.0	95 ± 2.6
	Mixed herbaceous species	67.1 ± 1.3	63 ± 8.0
	Pricklypear	87.7 ± 1.7	80 ± 3.0
November 1989	Honey mesquite	63.4 ± 1.2	75 ± 5.0
	Huisache	62.9 ± 1.6	78 ± 8.5
	Mixed herbaceous species	60.5 ± 1.5	60 ± 7.0
	Pricklypear	91.9 ± 1.0	73 ± 4.5
January 1990	Mixed herbaceous species	40.4 ± 3.5	51 ± 7.5
	Pricklypear	91.2 ± 0.5	74 ± 8.2
February 1990	Dormant herbaceous species	14.6 ± 5.6	53 ± 10.2
	Mixed herbaceous species (green)	78.4 ± 1.5	83 ± 7.0
	Pricklypear	88.3 ± 0.8	69 ± 8.0
May 1990	Honey mesquite	60.9 ± 1.2	85 ± 6.9
	Huisache	59.1 ± 0.6	79 ± 6.7
	Mixed herbaceous species	69.6 ± 2.9	75 ± 5.2
	Pricklypear	93.2 ± 0.5	67 ± 10.4

[a]Standard deviation.

caused it to absorb a larger percentage of the MIR radiation (Gates et al. 1965; Gausman et al. 1977, 1978).

In January 1990, pricklypear had significantly lower visible (0.65 μm) reflectance than mixed herbaceous species and soil, whereas its NIR (0.80–0.85 μm) reflectance was higher than that of mixed herbaceous species and soil (Table 1). Pricklypear had significantly lower MIR (1.50–1.75 μm) reflectance than mixed herbaceous species and soil in January. In February 1990, the visible reflectance of pricklypear did not differ from that of mixed herbaceous species. At the NIR wavelengths, however, pricklypear had a significantly different reflectance value than that of the associated species and soil. The MIR reflectance of pricklypear was lower than that of the associated species and soil in February. For the May 1990 sampling date, pricklypear had a visible reflectance value similar to that of huisache, while its NIR reflectance did not differ from that of mixed herbaceous species. In the MIR range, however, the reflectance value for pricklypear was significantly lower than for all other canopy conditions. Although pricklypear had distinct visible and NIR reflectance on some of the sampling dates (January and February), the spread between its mean reflectance values and that of the associated plant species and soil was not as great as in the MIR spectral region for the January, February, or May study periods. The distinct separation of pricklypear in the MIR spectral region on all dates is attributable to its greater water content on all dates (Table 2). These data indicate that the MIR spectral region is best for distinguishing pricklypear from associated vegetation and soil.

Figure 1-A, B, and C show red, NIR, and MIR ground video images, respectively, of pricklypear in a rangeland area near Weslaco, Texas. In the visible red image (Fig. 1A) pricklypear has a gray tone which is attributed to absorption by chlorophyll in this part of the spectrum (Myers et al. 1983), whereas in the NIR band (Fig. 1B) pricklypear has a whitish-gray response because green vegetation is reflective in this spectral region (Myers and Allen 1968). The dark gray to almost black tone of pricklypear in the MIR video image (Fig. 1C) is attributed to its succulent tissue and subsequent high water content (Table 2) which absorbed a large percentage of the MIR radiation (Gausman et al. 1978, Everitt et al. 1986a).

Red, NIR, and MIR aerial video images of a rangeland site populated with pricklypear are shown in Figures 2-A, B, and C, respectively. The imagery was obtained in January 1990 near Alice, Texas. The arrows on the images point to a stand of pricklypear plants. Other pricklypear plants are scattered throughout the images. No other shrubs are detectable in the images because they are deciduous in winter. In the red image (Fig. 2-A) pricklypear has a variable gray signature that can generally be detected, but some plants are difficult to distinguish from the lighter gray background signature of mixed herbaceous vegetation. Soil has a whitish gray signature. Pricklypear has a gray to light gray signature in the NIR image (Fig. 2-B) that is difficult to separate from the associated mixed herbaceous species and soil. In the MIR image (Fig. 2-C) pricklypear has a dark gray to black image tone that can generally be separated from the gray and whitish tones of mixed herbaceous species and soil, respectively. The high water content of pricklypear apparently contributed greatly to its pronounced dark signature in the MIR image (Gausman et al. 1977, 1978), but in-canopy shadowing probably also attributed to its dark image response (Richardson et al. 1975).

Ground truth surveys from 7 scattered sites selected from MIR video images of rangeland areas near Alice, Campbellton, Edinburg, and Mercedes, Texas, in January and February 1990 resulted in correct visual identification of pricklypear at all locations. Pricklypear had a similar image response at all locations and could be distinguished best on imagery acquired at 900–1,200 m (recorded horizontal ground pixel size 0.75–0.95 m). Pricklypear could be distinguished in some of the visible red imagery obtained at these locations, but its signature was not as distinct as that in the MIR imagery. An analysis of the NIR imagery from these areas showed that pricklypear usually could not be distinguished in this spectral band.

Figure 2-D shows the computer classification of the MIR (Fig. 2-C) video image. Pricklypear has a white code in the computer classification. A visual comparison of the computer-classified MIR image to the conventional MIR image showed that the computer generally identified most of the pricklypear plants. The computer estimated that 3.9% of the image was pricklypear, whereas the computer estimated that 5.0% of the photointerpreter's overlay map of the area was made up of pricklypear. Ground truth data indicated that the photointerpreter's estimate of pricklypear cover was probably more accurate than the computer estimate in this instance. The computer did not identify some of the small pricklypear plants that were visible to the photointerpreter. However, the disagreement could also be contributed to the training of the photointerpreter since subjective boundary lines are drawn due to the grading of pricklypear and soil or herbaceous plant species from one to another. Nonetheless, these results indicate that pricklypear populations can be quantified on MIR video imagery.

Although pricklypear had significantly lower MIR (1.50–1.75 μm) canopy reflectance (Table 1) than all other canopy conditions on all dates, it could not always be distinguished on aerial MIR imagery. We found that in-canopy shadowing of honey mesquite, huisache, and other associated shrubs often produced a dark gray to black signature that made it difficult to distinguish pricklypear from these species during the growing season. Pricklypear could usually be separated from the larger woody plant species by its typical round shape and smaller stature, but small shrubs and pricklypear often had a similar MIR signature. A qualitative analysis of the red and NIR imagery obtained during the growing season showed that pricklypear usually could not be differentiated in these spectral bands. Thus, our findings indicate that the opti-

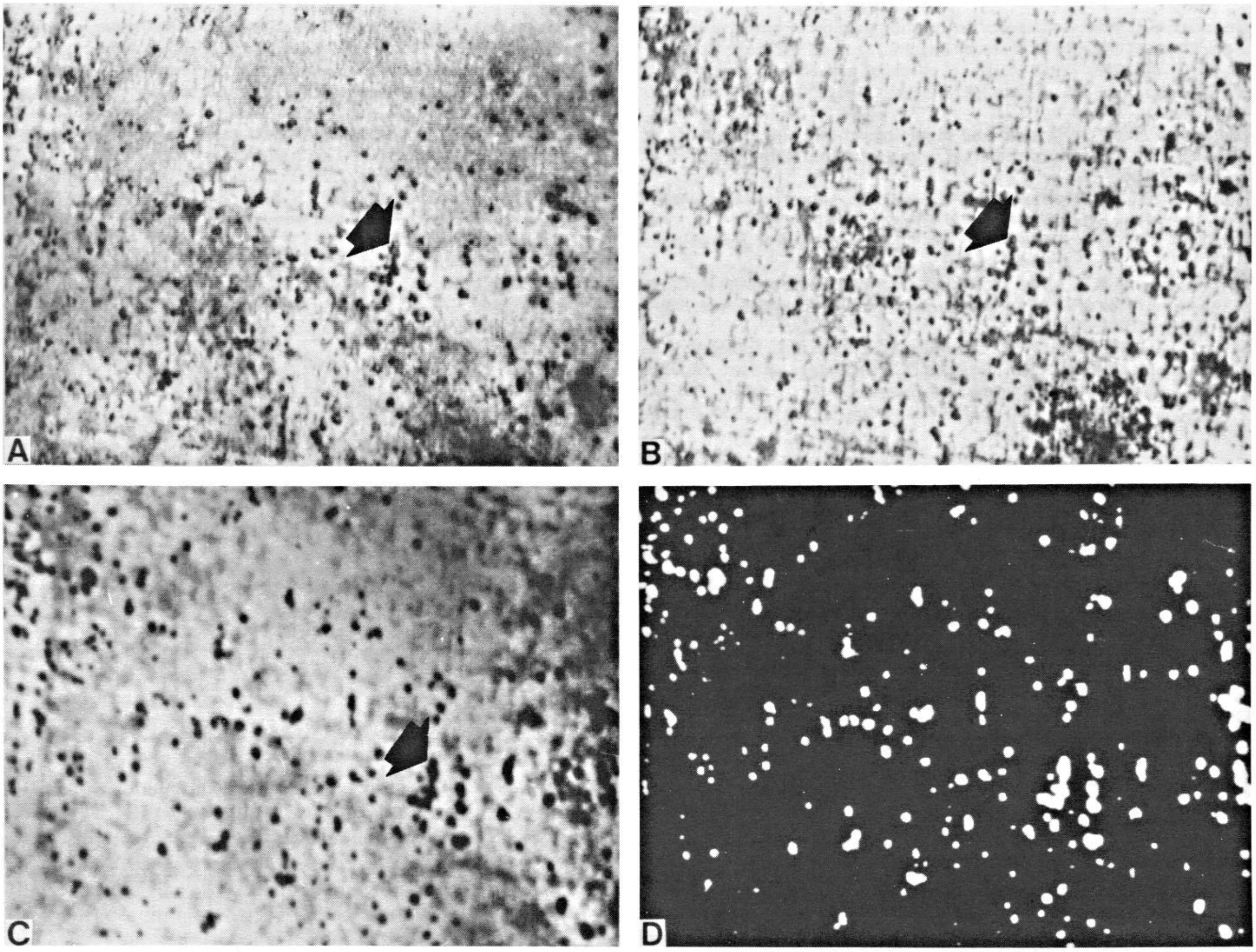

Fig. 2. Red (A), near-infrared (B), and mid-infrared (C) aerial video images of a rangeland area populated with pricklypear and computer classification (D) of the mid-infrared image. The imagery was acquired at an altitude of 1,050 m near Alice, Texas on January 25, 1990.

mum time to do MIR video aerial surveys to distinguish pricklypear would be in the January–February period when the majority of associated woody plant species lose their foliage.

Conclusions

Our results indicate that MIR video imagery may be a potentially useful tool to remotely distinguish pricklypear populations from other cover types on south Texas rangelands. Aerial surveys should be made in January–February when most associated woody plant species lose their foliage. Image analyses showed that pricklypear populations could be differentiated quantitatively. The capability to remotely distinguish and quantify pricklypear on rangelands should be useful to range and wildlife resource managers who are interested in monitoring its distribution and population.

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