J. Range Manage.
45:189-193, March 1992

Airborne laser measurements of rangeland canopy cover and distribution

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Abstract

Studies were made at 2 rangeland areas in south Texas to measure canopy cover and distribution with an airborne laser profiler. In a comparison of laser and ground measurements of canopy cover on the same eighteen 30.5-m segments at the Yturria area, laser measurements of canopy cover ranged from 1 to 89% and were correlated significantly ($r^2 = 0.89$) with ground measurements (1 to 88%) on the same eighteen 30.5-m segments. Comparisons of laser measurements of canopy cover for 500- and 940-m segments with an average of three 30.5-m ground measurements of canopy cover made within these segments were also significantly correlated ($r^2 = 0.95$). Topography, vegetation height, and spatial distribution of canopy cover for 6- to 7-km flightlines were also measured with the laser profiler. Airborne laser measurements of land surface features can provide quick and accurate measurements of canopy cover and distribution for large areas of rangeland. Accurate and timely data on the amount and distribution of plant cover are valuable for understanding vegetation characteristics, improving estimates of infiltration, erosion, and evapotranspiration for rangeland areas, and making decisions for managing rangeland vegetation.

Key Words: remote sensing, landscape, shrubs, brush, evapotranspiration

Rangelands cover almost half the earth's surface (Williams et al. 1968). Much of this rangeland occurs in arid and semiarid regions (Branson et al. 1981) and varies widely in canopy height, distribution, and cover (Tueller 1982). Kinds and amounts of vegetation cover have long been recognized as important factors affecting infiltration, erosion, and evapotranspiration (Gifford 1984). Data on the distribution of canopy cover and its change in time and space can be used for understanding, modeling, and managing infiltration, erosion, evapotranspiration, and plant growth for rangeland areas.

Current methods for measuring canopy cover typically incorporate ground measurements with line-intercept or line-transect methods (Canfield 1941, Eberhardt 1978). These methods are labor intensive and can be somewhat subjective in their application. Our purpose is to describe an alternative method using an airborne laser profiler to measure canopy height, cover, and spatial distribution on large areas of rangelands quickly and efficiently.

Study Area

The study was conducted on 2 rangeland areas in the South Texas Plains vegetation region. The climate is mild at both locations with short winters and warm temperatures throughout the year. The average growing season exceeds 325 days (Hatch et al. 1990).

The La Joya area is 6 km north of the Rio Grande River, about 140 km inland from the Gulf of Mexico in Hidalgo County, Texas. Average annual precipitation is 49 cm. The flightline at the La Joya area crossed 2 range sites, one a sandy loam and the other a red sandy loam. Soil of the sandy loam site is a Brennan fine sandy loam whereas that on the red sandy loam site is a Delmita-Randado soil complex (Jacobs 1981). The Brennan series is a member of the fine-loamy, mixed, hyperthermic family of Aridic Haplustalfs. The Delmita series is a member of the fine-loamy, mixed, hyperthermic family of Petrocalcic Palenstalfs, and the Randado series is a member of the loamy, mixed, hyperthermic, shallow family of Petrocalcic Ustollic Paleargids.

Honey mesquite (*Prosopis glandulosa* Torr.) is the dominant woody species at the La Joya site. Other woody species include lime pricklyash (*Zanthoxylum fagara* [L] Sarg.), bluewood (*Condalia hookeri* M.C. Johnst.), blackbrush acacia (*Acacia rigidula* Benth.), desert hackberry (*Celtis pallida* Torr.), and cenizo (*Leucophyllum frutescens* [Berl.] I.M. Johnst.). Pricklypear cactus (*Opuntia lindheimeri* Engelm.) is also present along with a variety of warm-season grasses and forbs. The vegetation community along the flightline was relatively uniform, varying primarily in density and height. Although the area is used for cattle grazing, there have been no major management efforts to control shrubs.

The Yturria area in Willacy County, Texas, is about 100 km northeast of the La Joya area and is about 35 km inland from the Gulf of Mexico. Average annual precipitation is 68 cm. The area is a sandy loam range site composed of a Defina fine-sandy loam soil. The Defina series is a member of the fine-sandy loam, mixed hyperthermic family of Aquic Paleustalfs. In contrast to the La Joya area, intensive management efforts to control woody vegetation at the Yturria area have led to a shrub-cluster type of vegetation comprised of dense stands of brush interspersed with large open areas. Brush stands are dominated by large honey mesquite trees (6 to 8-m) in the overstory with desert hackberry, bluewood, and lime pricklyash in the understory. Open areas are dominated by brush regrowth 1- to 3-m tall or false broomweed (*Ericameria austrotexana* M.C. Johnst.), a subshrub usually less than 1-m tall. Several species of warm-season grasses and forbs are found throughout.

Methods and Materials

A laser profiler mounted in a small twin engine aircraft was used to measure the distance between the aircraft and the landscape surface as defined by any object (i.e., soil, rock, vegetation, man-made structure) reflecting the laser pulse (Ritchie and Jackson

Robert Parry of the Hydrology Laboratory and Mario Alaniz of the Remote Sensing Unit assisted in the collection and analyses of the data.
Manuscript accepted 22 July 1991.

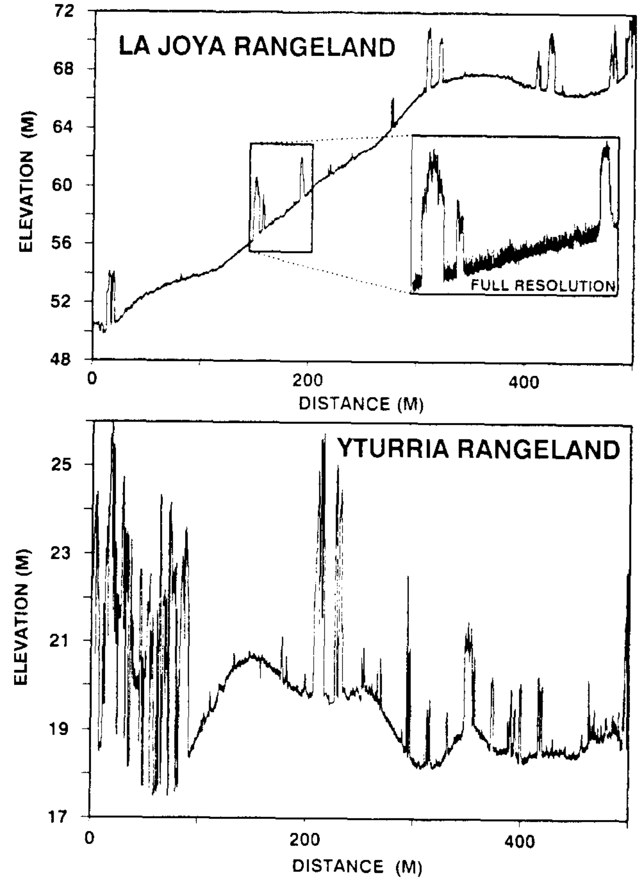

Fig. 1. Laser profiles of landscape surface for representative flightline segments at the La Joya (A), Hidalgo County, Texas, 28 June 1989 and Yturria (B), Willacy County, Texas, 24 July 1990 using averages of consecutive sets of 8 laser measurements. Inset in A shows non-averaged data from 8,192 laser measurements corrected to depict the approximate elevation.

1989). The aircraft flew at an altitude of about 150-m and at a speed of 60-m per second. The laser was a pulsed gallium-arsenide diode laser, transmitting and receiving signals at a wavelength of 0.904 μm. The laser operated at 4,000 pulses per second. Under these operating parameters, a vertical distance measurement from the aircraft to landscape surface occurred at 1.5-cm intervals along the flightline. The laser is designed to have a vertical recording accuracy of 5-cm on a single measurement.

Data collected by the laser were recorded digitally on a portable personal computer and stored on a fixed disk along with data from a gyroscope and an accelerometer which were used to correct the laser data for aircraft motion. A video camera, borehole-sited with the laser, recorded a visual image of the flightline. The video record was annotated with consecutive numbers and clock time every 1/60th of a second. The video frame number was recorded simultaneously with the digital laser data to allow precise location of the laser data and the video data.

Elevation was calculated for each laser measurement based on known elevations along the flightlines. Ground surface elevation was defined as the minimum elevations along a laser flightline segment. These minimum values were determined by calculating a moving minimum elevation for 21 laser measurements; some manual editing of these minimum elevations was required in areas of dense vegetation cover. It was assumed that these minimum elevations represented ground surface while anything above the minimum was vegetation. The height of vegetation was determined by subtracting the minimum measurements from the actual laser measurements at a measurement point.

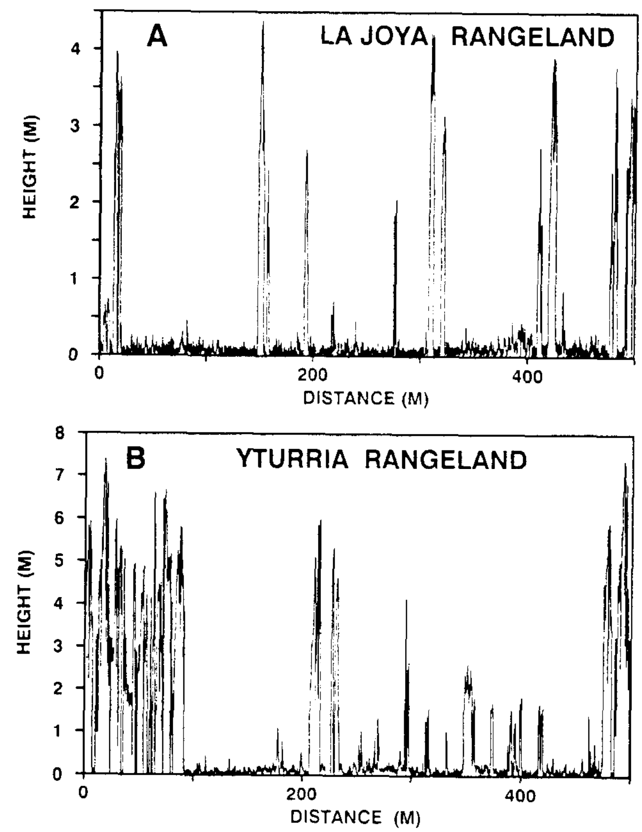

Fig. 2. Laser profile of vegetation heights for the same flightlines in Figure 1. Vegetation height was calculated as the difference between minimum ground elevation and the landscape surface.

Canopy cover was determined by height category by counting the number of laser measurements in a height category and dividing by the total number of laser measurements for a line segment. Canopy heights were determined by 0.5-m height increments and then combined to determine the canopy cover for heights greater than 0.5-m and greater than 1.0-m used in these analyses.

Spatial distribution of percent canopy cover along the flightlines was calculated for canopy heights greater than 0.5-m by determining the percent canopy cover for the first 30.5-m of a flightline segment, incrementing 1 laser measurement and calculating canopy cover for the next 30.5 m. This gave an integrated average for the canopy cover along the flightline for 30.5-m increments. A moving standard deviation of the canopy heights was calculated in the same manner for 30.5-m intervals to determine the roughness of the landscape surface.

Two flightlines about 6,500- long and less than 20-m apart were flown at the Yturria area on 24 July 1990. Along the 2 flightlines, laser data and ground measurement for eighteen 30.5-m segments were analyzed and used for direct comparison of laser and ground measurements for the same sites. Canopy cover was also determined for six 500-m segments on each flightline by averaging 8 consecutive laser measurements. Three ground measurements of cover were made in each of the six 500-m segments and averaged to estimate ground cover for each of the 6 segments.

A single flightline 6,580-m long was flow at the La Joya area on 28 June 1989. Seven segments, each 940-m long, were analyzed by averaging 8 consecutive laser measurements to determine cover for these segments. Three ground measurements of cover were made in each of the seven 940-m segments and averaged to estimate ground cover for each of the 7 segments.

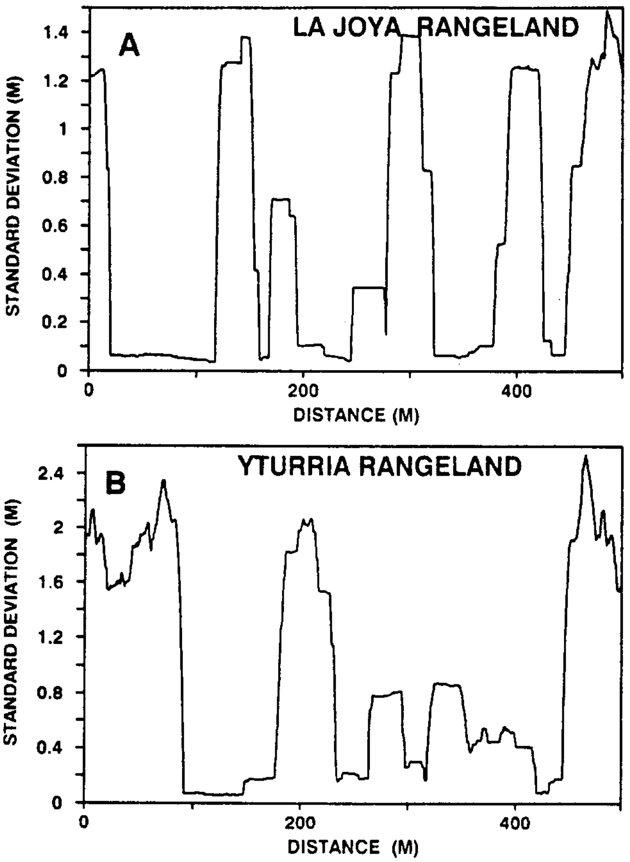

Fig. 3. Standard deviations of the laser measurements for 30.5-m increments for La Joya (A), Hidalgo County, Texas, 28 June 1989 and Yturria (B), Willacy County, Texas, 24 July 1990 calculated from the data shown in Figures 2A and 2B, respectively.

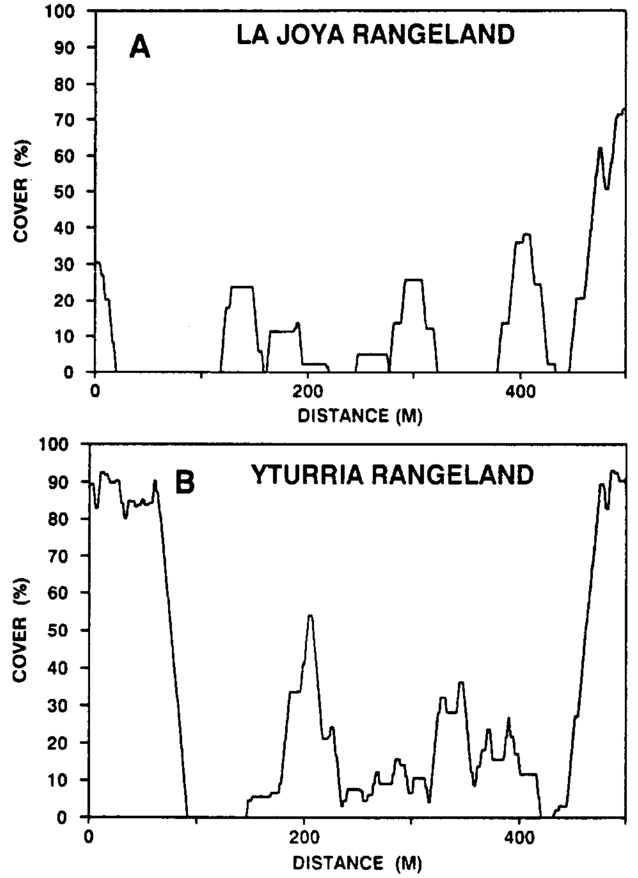

Fig. 4. Spatial distribution of canopy cover for 30.5-m increments for vegetation greater than 0.5-m tall for La Joya (A), Hidalgo County, Texas, 28 June 1989 and Yturria (B), Willacy County, Texas, 24 July 1990. Cover was calculated from data shown in Figures 2A and 2B, respectively.

The line-intercept method (Canfield 1941, Eberhardt 1978) was used to make ground measurements of canopy cover for 30.5-m segments along the flightlines. Measurements of canopy cover were made for canopies intercepting the line transects at heights greater than 0.5-m and greater than 1.0-m. The video recorded during the laser flights was used to locate ground measurement sites as close as possible to the flightlines.

Results and Discussion

Variable ground surface topography and the presence of objects above the ground surface are evident in the laser data (Fig. 1). The 3 protrusions in the inset (Fig. 1A) were identified as shrubs or small trees in the video image obtained concurrently with the laser measurements. Vegetation height (Fig. 2) was calculated as the distance above the minimum ground elevation on the laser segments. Individual shrubs were represented by individual spikes in the profile, while clumps of shrubs (more common at the Yturria area) were represented by aggregates of spikes whose minima did not reach the ground.

The height variation in the canopy (Table 1) is shown by the distribution of cover by 0.5-m height increments for three 30.5-m laser segments along the 2 flightlines measured with the laser profiler at Yturria. Most of the measurements were between 0.0 to 0.5-m although canopy heights up to 7.5-m were encountered. These data are typical of total flightlines and the variability in the vegetation heights at Yturria and La Joya.

Table 1. Laser measurements of percent canopy cover by height (m) for 2 flightlines at the Yturria area, Willacy County, Texas, 24 July 1990. Each site represents a 30.5-m segment along the flightline at about the same location.

Height	Canopy Cover					
	Flightline 1			Flightline 2		
	4A	4B	4C	4A	4B	4C
(m)		%			%	
0.0–0.5	81.6	90.2	43.4	86.7	95.5	27.3
0.5–1.0	5.9	8.5	1.4	3.8	4.3	1.5
1.0–1.5	7.3	1.3	1.5	4.8	0.2	2.0
1.5–2.0	5.2		1.8	4.6		3.7
2.0–2.5			3.0	0.1		9.6
2.5–3.0			1.3			15.0
3.0–3.5			0.8			11.1
3.5–4.0			3.0			7.6
4.0–4.5			7.1			7.6
4.5–5.0			17.1			4.5
5.0–5.5			11.8			7.6
5.5–6.0			2.1			2.5
6.0–6.5			3.0			
6.5–7.0			2.6			
7.0–7.5			0.3			

A distribution of ground and canopy roughness along the flightlines was measured by the standard deviation of canopy heights (Fig. 3) for 30.5-m segments. Standard deviations of 5 to 6-cm were measured between clumps of vegetation in both study areas with standard deviations greater than 1-m in shrub-dominated areas. Such measurements of landscape roughness may provide valuable data on aerodynamic roughness of the landscape needed for mak-

Table 2. Comparison of percent canopy cover measured using the line transect method and laser profiler at the Yturria area, Willacy County, Texas, 24 July 1990. Both laser and ground measurements are for 30.5-m transects at about the same location on the ground.

Segment	Plants > 0.5-m Tall			Plants > 1.0-m Tall		
	GR[1]	FL 1[2]	FL 2[3]	GR	FL 1	FL2
	%			%		
1A	2.0	5.6	3.3	2.0	1.9	0.8
1B	7.8	7.2	7.8	2.3	1.8	2.5
1C	12.4	13.1	10.1	11.6	5.3	3.9
2A	56.1	61.3	56.6	54.8	59.2	47.3
2B	20.1	21.8	22.1	3.2	2.1	7.0
2C	52.2	48.7	42.5	52.2	47.3	39.7
3A	45.3	63.7	49.0	45.3	61.4	45.0
3B	39.3	42.7	44.9	39.3	40.7	43.1
3C	29.2	29.7	24.4	18.7	22.0	11.5
4A	17.7	18.4	13.3	17.7	12.6	9.5
4B	6.1	9.8	4.5	1.3	1.3	0.2
4C	63.7	56.6	72.7	57.4	55.2	71.2
5A	79.5	83.6	89.1	79.5	83.5	88.3
5B	55.8	61.3	48.6	55.8	60.6	46.0
5C	53.6	46.3	54.7	52.8	45.8	54.1
6A	79.7	73.7	66.0	79.7	71.0	63.7
6B	87.8	79.5	72.2	87.8	78.5	64.8
6C	45.5	69.3	70.9	45.5	68.3	70.5

[1]Ground—Data from line intercept method.
[2]FL 1—Data from laser flightline 1.
[3]FL 2—Data from laser flightline 2.

ing estimates of evapotranspiration in rangeland areas. Further research is needed to determine the usefulness of this roughness data.

Canopy cover also varied in spatial distribution within and between the 2 areas (Fig. 4). The patterns of spatial distribution of canopy cover along the flightlines are unique. The difficulty in locating sample sites that will give typical cover measurements with the line-intercept or transect method for short segments is illustrated by these patterns. Canopy cover ranged from 0 to 90% along the 500-m segments and was dependent on where a 30.5-m segment started. Further analyses are necessary to relate spatial patterns measured with the laser profiler to plant community and ecological characteristics.

At the Yturria area, canopy cover greater than 0.5-m tall measured with the laser ranged from 3.3 to 89.1% as compared to 2 to 87.8% for the eighteen 30.5-m ground measurements at the same sites (Table 2). The range was from 0.2 to 88.3% for laser measurements and 1.3 to 87.8% for ground measurements for canopy cover greater than 1-m tall at the same sites. The laser measurements compared well with the cover measured on the ground made at the same sites at the Yturria area (Fig. 5A). When the greater than 0.5-and 1.0-m data were combined, the coefficient of determination (r^2) was 0.89 for the linear relationship between laser and ground measurements of cover for the same 30.5-m segments. The data points were uniformly distributed around a 1:1 line (Fig. 5A). Thus the laser profiler method was measuring canopy cover similar to that measured on the ground by the line-transect method.

For longer segments, laser-measured canopy cover at the La Joya area for vegetation cover greater than 0.5-m tall ranged from 17.9 to 41.9% for the seven 940-m laser segments and was 23.9% for the 6,580-m flightline (Table 3). For canopy greater than 1-m tall, the canopy cover ranged from 3.7 to 29.7% for the 7 laser segments and was 15.7% for the entire flightline. The range for the average for 3 ground measurements on each of the 7 segments was 19.4 to 43.5% for canopy greater than 0.5 m and 4.2 to 33.8% for canopy greater than 1.0 m. Again similar patterns were measured with the laser and ground data.

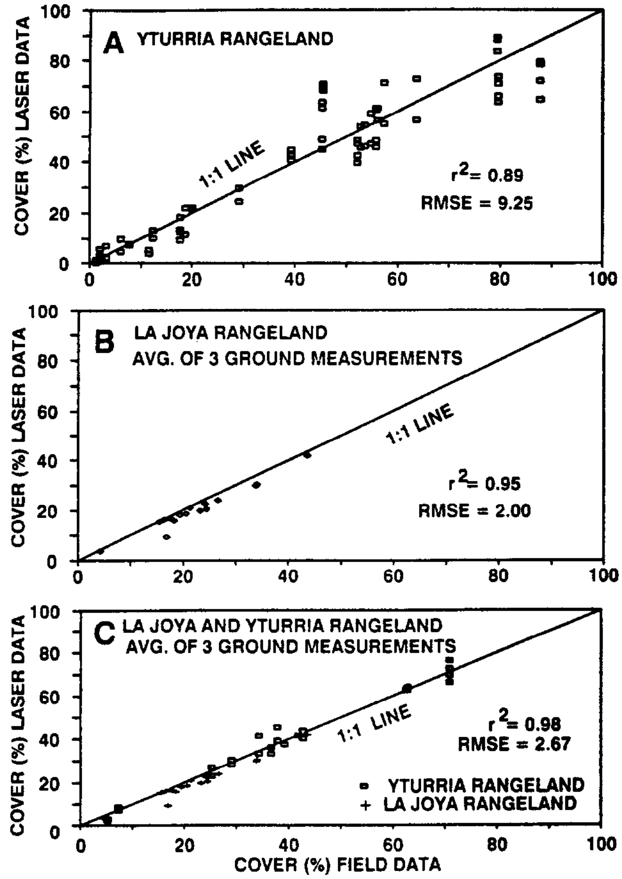

Fig. 5. Comparison of the relationship between ground and laser measurements of canopy cover greater than 0.5-m and 1.0-m tall. Data are shown for the Yturria area (A), Willacy County, Texas, 24 July 1990 comparing individual laser and ground cover measurements for the same 30.5-m segments, the La Joya area (B), Hidalgo County, Texas, 28 June 1989 for an average of 3 ground measurements with 940-m laser segment, and for both areas (C) with an average of 3 ground measurements with 940-m and 500-m line segments.

The ground and laser measurements of canopy cover at the La Joya area were compared. The averaged ground measurements were higher than the laser measurements for the canopy cover greater than both 0.5-m and 1-m. The coefficient of determination (r^2) was greater than 0.95 for the relationship between ground and laser measurements for the La Joya area (Fig. 5B). However, the ground and laser measurements of canopy cover differed (P>0.05) when compared with a paired t-test. This difference was probably due to the comparison between an average of three 30.5-m ground measurements and cover measurements for 940-m laser segments.

The cover measurements calculated from the 940-m segments from the La Joya area (Table 3) and 500-m segments from the Yturria area (Table 4) with the average of 3 ground measurements for each of these segments were compared and a coefficient of determination (r^2) of 0.98 was calculated for the combined data set (Fig. 5C).

Since similar patterns were measured with the ground and laser measurements for the same 30.5-m segments at the Yturria area (Fig. 5A), differences between these ground and laser measurements of canopy cover at the same site are probably due to the comparison of 30.5-m ground and laser segments that are not at exactly the same line transect. The differences between averaged ground measurements and laser measurements for longer segments (Figs. 5B and 5C) would be due to the comparison of an average measurement for three 30.5-m ground segments with longer laser

Table 3. Comparison of percent canopy cover measured using the line transect method and laser method at La Joya range area, Hidalgo County, Texas, 28 June 1989. Each laser segment is 940-m long, while ground measurements are the average of three 30.5-m ground measurements using the line transect method along each 940-m segment.

Segment	Plants > 0.5-m Tall		Plants > 1.0-m Tall	
	Ground[1]	Laser[2]	Ground	Laser
	%		%	
1	20.5	18.4	16.3	16.0
2	21.3	20.8	15.4	15.2
3	23.3	19.6	17.7	16.2
4	24.6	20.3	16.8	9.2
5	19.4	17.9	4.2	3.7
6	34.0	30.3	24.3	22.4
7	43.5	41.9	33.8	29.7
All[3]	26.7	23.9	18.3	15.7

[1]Ground—Canopy cover is the average of 3 measurements using line transect method.
[2]Laser—Data from laser flightline.
[3]All—Represent the canopy cover for the 6,580-m flightline.

segments. However, ground measurement of the canopy cover on 500- or 940-m transects would be too time consuming and costly; thus a comparison could only be made between averages and the longer laser segments. The cluster of data around the 1:1 line (Figs. 5A, 5B, and 5C) shows that the ground transects and the laser transects are measuring similar patterns. The difference between the 2 methods was probably due to the inability to locate the ground measurements and the flightline on exactly the same transects.

Conclusion

Estimates of patterns and density of canopy cover measured with an airborne laser and line-transect ground measurements at the same sites were similar and significantly correlated, thus an airborne laser is a potential technique to measure canopy cover of large areas of rangelands quickly and quantitatively. Spatial patterns and patchiness of vegetation height, cover, and roughness can also be determined. Such data are time-consuming and expensive to collect with conventional methods for equivalent-sized areas and could be impossible to collect in certain cases due to the inaccessibility of some rangeland areas. Data on the amount and distribution of plant canopy cover will be valuable for understanding vegetation patterns and characteristics, improving estimates of infiltration, erosion, and evapotranspiration for rangeland areas, and making decisions about managing woody vegetation.

Table 4. Comparison of percent canopy cover measured using the line transect method and laser method at Yturria range area, Willacy County, Texas, 24 July 1990. Each laser segment is 500-m long, while ground measurements are the average of three 30.5-m ground measurements using the line transect method along each 500-m segment.

Site	Ground[1]	FL 1[2]	FL 2[3]
		%	
	Canopy Cover for Plants >0.5-m Tall		
1	7.4	8.7	7.1
2	42.8	43.9	40.4
3	37.9	45.4	39.4
4	29.2	28.3	30.2
5	63.0	63.7	64.1
6	71.0	76.4	69.7
ALL[4]	41.9	44.4	41.8
	Canopy Cover for Plants >1.0-m Tall		
1	5.3	3.0	2.4
2	36.7	36.2	33.2
3	34.4	41.4	33.2
4	25.5	23.0	27.0
5	62.7	63.3	62.8
6	71.0	72.6	66.3
ALL	39.3	39.9	37.5

[1]Ground—Canopy cover is the average of 3 measurements using line transect method.
[2]FL 1—Data from laser flightline 1.
[3]FL 2—Data from laser flightline 2.
[4]ALL—Represent the canopy cover for the 6,500-m flightline.

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