J. Range Manage.
47:385-391 September 1994

Airborne synthetic aperture radar analysis of rangeland revegetation of a mixed prairie

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Abstract

Microwave radar is a potentially useful tool for monitoring the condition of the rangeland. A study was conducted in a mixed prairie community at the Agriculture Canada Research Substation at Onefour, Alberta in 1991 to examine the effects of historical management on synthetic aperture radar (SAR) data obtained from 2 aircraft flights, 24 May 1991 and 1 August 1991. Ground-truthing expeditions were conducted on the same days to obtain estimates of vegetation amounts, species distribution and soil moisture. A former grazing experiment established in 1955 and abandoned 20 years ago enabled comparison of 3 grazing treatments, continuous, rotation and free choice superimposed on native range, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and Russian wildrye (*Elymus junceus* Fish.). The ground data and imagery were integrated in a Geographic Resource Analysis Support System (GRASS). Fields that had been cultivated and seeded to Russian wildrye had higher radar backscatter than native range. The radar backscatter from crested wheatgrass fields was similar to native range in May but higher than native range in August. Radar backscatter was positively correlated with number of years since seeding with Russian wildrye. Generally there was little difference in radar backscatter with grazing treatment. Correlation analyses between radar digital number extracted from the ground truth sites and vegetation and soil parameters revealed, depending upon swath mode, significant relationships between radar backscatter and the amount of certain grass species, radar backscatter and canopy moisture, and radar backscatter and soil moisture in May. A significant negative correlation was observed between radar backscatter from the August images, in both swath modes, and percent ground cover. The results of this study indicated a role for SAR imagery in evaluating range characteristics.

Key Words: radar backscatter, seeding, Russian wildrye, crested wheatgrass, canopy moisture

The mixed prairie ecoregion of the Northern Great Plains in Canada occupies an area of 24 M ha (Willms and Jefferson, 1993). Monitoring this vast resource by conventional methods is both time consuming and labour intensive. Remote sensing offers a potentially attractive alternative for assessing rangeland condition and productivity. A good relationship exists between range productivity and LANDSAT MSS visible and infrared (VIR) data (Brown et al., 1983). However, the occurrence of few cloud free days even in semi-arid regions reduces the potential for monitoring rangelands using multi-temporal visible and infrared data. Over Western Canada the chance of obtaining a LANDSAT image with less than 20% cloud cover is only 29% (Brown et al., 1984).

The cloud penetrating properties of microwaves permit the use of satellite radar in all weather conditions and enable acquisition of strategic date imagery and multi-temporal data on a reliable basis. These properties together with the greater availability of data from the European Remote Sensing Satellite (ERS-1) and the Japanese Earth Resources Satellite (JERS-1), which were launched recently, and the Canadian Space Agency RADARSAT which is due to be launched in 1995, has stimulated interest in the use of this technology for agricultural monitoring (Brown et al., 1993). The assessment of synthetic aperture radar data from an agricultural perspective is necessary in the development of methods and techniques which will maximize the extraction of crop and soil information. Airborne synthetic aperture radar, hereafter referred to as airborne radar, provides a tool for increasing our understanding of the potential of satellite radar data for monitoring ground vegetation.

Radar backscatter, the microwave energy reflected back to the radar sensor, is primarily influenced by the dielectric constant and surface roughness of the target. As the dielectric constant of water (~ 80) is much greater than that of dry vegetation or soil (~ 3 to 5) a small change in moisture content of either vegetation or soil causes a large change in the dielectric properties. The volumetric water content of vegetative canopies (Brakke et al., 1981, Major et al., 1991a) and soils (Dobson and Ulaby, 1986) therefore influences radar backscatter. On the tallgrass prairie in Kansas, Martin et al. (1989) found that C-band (4.75 GHz, 63 mm wavelength) radar backscatter was influenced by green live vegetation as opposed to senescent vegetation which is consistent with moisture being a driving factor.

Target roughness can also influence radar backscatter. Smooth surfaces scatter little or no radar energy while rough surfaces scatter more. Major et al. (1991b) found that tillage increased soil roughness and radar backscatter; the effects being more evident in C- than Ku- or L-band. C-band is microwave energy of wavelength 3.8 to 7.5 cm while the Ku- and L-band have microwave energies of 1.7 to 2.4 cm and 15 to 30 cm, respectively. Incidence angles of 5-10° can minimize the effects of target roughness, however, most radar systems function at incidence angles much greater than these.

This study was conducted to further document the use of C-band

The authors gratefully acknowledge the technical assistance of Mr. Bruce Beasley, Mr. Bob Gschaid, Mr. Craig Andrews, Mr. Greg Travis and Mr. Mike Strate of the Agriculture Canada Research Station, Mr. Ian Kosokowsky and Mr. Roy Penniket of Terrain Resources, Inc., Lethbridge, AB, who worked so diligently procuring ground-truthing data; Mr. Sylver Smoliak for recalling and recording the history of the substation; Mr. Rod Bennett of Alberta Agriculture and his staff for their administrative assistance; Mr. John Naunheimer of the Canada Centre for Remote Sensing for his assistance with the SAR tapes; Alberta Agriculture Research Institute for funding assistance; and, Mr. Dave Satnik and Dr. Ron Owen, Central Washington University, for assistance with GRASS. This paper is Contribution number 3879262 of the Lethbridge Research Station.
Manuscript accepted 6 Jan. 1994.

airborne radar for assessing rangeland condition. C-band was chosen because RADARSAT will carry a C-band HH polarisation radar. HH polarisation means the radar signal is transmitted and received in the horizontal plane. Application and analysis of radar data in agriculture is still in a relatively early stage of development and the characteristics of agriculturally relevant factors that determine radar reflectivity remain to be elucidated. Thus, ground data were collected at the same time as the airborne radar data to assist in determination of the vegetation and soil factors or characteristics which influence radar backscatter.

Materials and Methods

Site Description

The study was conducted in 1991 at the Agriculture Canada Research Substation at Onefour, Alberta (Lat. 49°, 0 to 11'N, Long. 110°, 20 to 33'W, elevation 920 m) (Figure 1). The region is mostly flat to gently rolling but, in places, is deeply cut by river valleys that are dry most of the year. Drainage is largely into sloughs, although the local drainage basin is a part of the Milk River system, which flows into the Missouri River in Montana.

The soils of the area are mainly light loams. The profile is associated with the residual rock formations which, in this case, are principally Bearspaw and Belly River shales. Practically all of the area has a solonized profile, with characteristic eroded pits due to the patchy removal of the A or surface horizon. These eroded pits may or may not support vegetation. The exposed B_1 horizon is usually dark in color and very hard which prevents or limits water penetration into the soil.

The climate of the region is characterized by low precipitation, a high rate of evaporation, great extremes of temperature, frequent high winds, and abundant sunshine. The average total annual precipitation is about 280 mm and the precipitation to evaporation ratio is about 0.35 (Hubbard and Smoliak, 1953). This is the principal climatic factor limiting plant growth. The average annual snowfall of 85 cm may appear relatively high, but much of it is not normally available for plant growth because the many warm chinook winds sublimate it before it can enter the soil.

The area is representative of the *Stipa-Bouteloua* community in the mixed prairie ecosystem described by Coupland (1961). Needle-and-thread (*Stipa comata* Trin. & Rupr.) and blue grama grass (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud) are the dominant species. Other important grasses include western wheatgrass (*Agropyron smithii* Rydb.), Junegrass (*Koeleria cristata* (L.) Pers.) and Sandberg's bluegrass (*Poa sandbergii* Vasey). Sedges (*Carex stenophylla* Wahl and *C. filifolia* Nutt.) are common. Common forbs include pasture sage (*Artemisia frigida* Willd.), dwarf phlox (*Phlox hoodii* Richards.), broom weed (*Gutierrezia diversifolia* sarothrae (Pursh) Britt. & Rusby), winter fat (*Eurotia lanata* (Pursh) Moa.), salt sage (*Atriplex nuttallii* S. Wats.) and hoary sage brush (*Artemisia cana* Pursh). Cactus (*Opuntia polyacantha* Haw.) is locally common. Little club moss (*Selaginella densa* Rybd.) is abundant throughout. The average annual dry matter production of this *Stipa-Bouteloua* community, over a 50 year period, has been estimated at 388 kg/ha (Smoliak, 1968). Since 1928 many of the pastures have been plowed and seeded to crested wheatgrass or Russian wildrye.

Synthetic Aperture Radar Acquisition and Processing

On 24 May 1991 and 1 August 1991, SAR C-band data were obtained using the Canada Centre for Remote Sensing (CCRS) Convair 580 (Livingstone et al., 1987). The frequency and wavelength of the C-band radar were 5.30 GHz and 5.66 cm, respectively. The radar data were collected in HH polarisation and in both the nadir and narrow swath modes (Table 1) to provide multi-parameter data sets across the station. The major difference between nadir and narrow swath modes is the incidence angle with nadir going from 0 to 74° and narrow going from 45 to 85°.

Table 1. Radar operating geometry for Canada Centre for Remote Sensing C-band airborne synthetic aperture radar.

Mode	Resolution[1] Azimuth	Range	Incidence angle	Swath width
	—— (m) ——		(°)	(km)
Nadir	6	6	0-74	22
Narrow	6	6	45-85	18

[1]Range resolution is in the direction perpendicular to the line of flight and azimuth resolution is in the same direction as the line of flight.

Four images were processed, a nadir and a narrow mode image for each of the 2 dates. The synthetic aperture radar data were processed at the Agriculture Canada Research Station using the Landsat Digital Imaging Analysis System (LDIAS). A 5 x 5 median filter which reduces speckle but preserves image integrity (Hutton and Brown, 1989) was performed on each image prior to importing them into the Geographical Resources Analysis Support System (GRASS). Each image was registered separately to the map indicating roads and fences illustrated in Figure 1. The resolution specified for the GRASS raster map containing the image was maintained at 6 m.

The image data were not calibrated for each date so the absolute digital number and tones of the imagery cannot be compared. Calibration allows one to compare digital numbers between 2 dates or

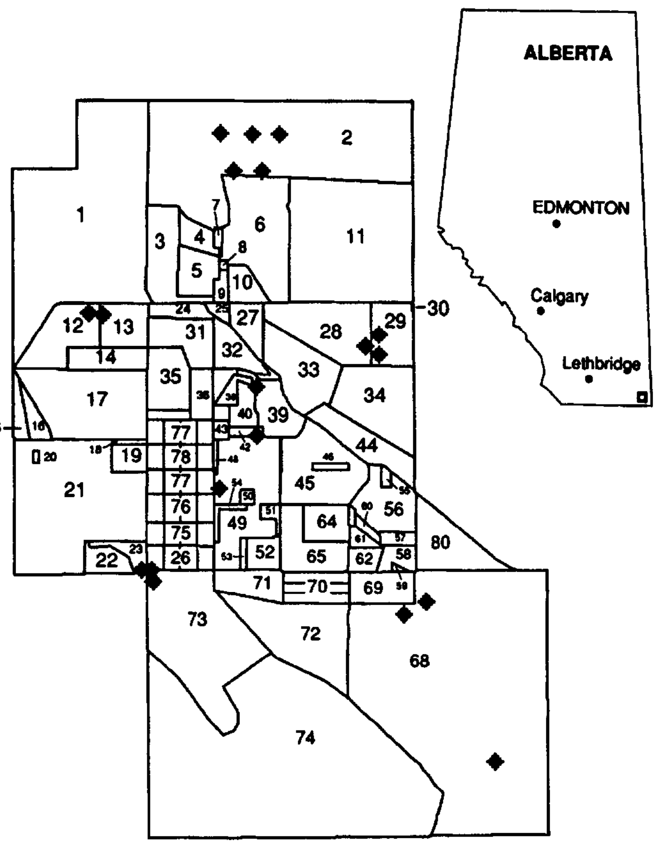

Fig. 1. Map of the Agriculture Canada Substation at Onefour, AB indicating field boundaries and numbers which correspond to Table 1 and sample sites.

sensors (relative calibration) or to relate digital number to a physical parameter of absolute radar backscatter. Calibration of airborne radar, a difficult and time-consuming problem, is described by Freeman (1992). Relative comparisons among selected targets are, however, valid. The data in this study were analyzed in 3 different components to determine the effects of seeding, the effects of plant community and the effects of soil and vegetation characteristics.

Effects of seeding

The mean digital number was extracted for each of 49 fields from

Table 2. Listing of fields used for radar backscatter analysis showing seeded grass, year of seeding and area.

Field	Vegetation	Year	Size	Date: May Nadir	Date: May Narrow	Date: August Nadir	Date: August Narrow
			(ha)	Digital number			
8[1]	Headquarters		5.1	73.3	98.7	60.7	113.5
70[1]	Grazing experiment		121.0	82.2	100.8	83.3	102.4
13	Native range		119.6	71.8	96.7	73.1	83.9
24	Native range		52.9	76.3	100.0	78.5	98.3
28	Native range		288.8	68.1	93.9	84.0	98.6
31	Native range		145.2	71.5	97.3	75.7	88.3
34	Native range		306.7	65.0	93.4	80.7	94.9
36	Native range		69.7	69.9	102.8	74.5	86.9
44	Native range		171.7	68.2	98.5	82.8	101.3
56	Native range		169.6	70.5	92.9	75.4	93.4
20	Crested wheatgrass	1928	3.7	55.7	79.4	62.6	72.6
46	Crested wheatgrass	1930	13.6	86.0	124.7	90.2	118.4
55	Crested wheatgrass	1932	10.9	69.4	99.6	88.6	117.3
53	Crested wheatgrass	1937	11.5	101.5	136.1	120.5	135.8
47	Crested wheatgrass	1938	5.2	79.2	107.9	90.2	114.4
48	Crested wheatgrass	1938	7.6	65.0	93.3	84.6	96.3
38	Crested wheatgrass	1940	29.6	62.7	88.0	94.9	95.8
66	Crested wheatgrass	1948	24.7	68.3	95.4	83.8	92.9
50	Crested wheatgrass	1950	11.3	68.9	89.7	74.7	87.4
51	Crested wheatgrass	1950	20.0	72.6	98.0	80.6	95.0
52	Crested wheatgrass	1950	64.8	87.3	117.9	112.2	122.8
54	Crested wheatgrass	1950	18.1	75.0	102.6	73.9	91.8
25	Crested wheatgrass	1961	21.1	69.2	92.8	84.9	115.8
63	Russian wildrye	1952	25.8	97.6	130.9	105.2	134.8
42	Russian wildrye	1956	19.6	82.3	108.6	109.3	119.8
57	Russian wildrye	1959	27.1	81.3	107.5	99.7	115.4
60	Russian wildrye	1959	15.2	85.1	115.9	101.2	120.3
40	Russian wildrye	1960	55.8	70.0	93.7	98.8	106.6
26	Russian wildrye	1960	97.7	82.2	111.1	98.2	128.0
9	Russian wildrye	1961	25.6	93.0	127.4	70.8	130.8
75	Russian wildrye	1961	92.8	73.3	100.9	87.0	110.0
61	Russian wildrye	1962	18.0	84.0	115.4	97.0	111.9
76	Russian wildrye	1962	109.3	87.6	118.3	83.0	107.4
62	Russian wildrye	1963	34.6	89.2	121.1	101.7	123.7
77	Russian wildrye	1963	93.2	79.8	111.9	84.7	106.9
18	Russian wildrye	1964	9.3	68.0	98.3	88.9	103.9
78	Russian wildrye	1964	101.3	73.2	105.9	85.1	100.6
64	Russian wildrye	1965	97.4	85.9	115.3	92.3	110.8
79	Russian wildrye	1965	92.8	72.8	101.1	83.8	101.6
49	Russian wildrye	1966	385.0	78.3	107.5	85.4	104.8
19	Russian wildrye	1967	456.6	69.1	102.0	75.3	89.6
15	Russian wildrye	1968	39.0	67.8	97.6	71.4	83.9
41	Russian wildrye	1968	41.3	74.2	111.3	96.2	112.0
43	Russian wildrye	1968	16.9	78.2	116.8	93.7	130.6
35	Russian wildrye	1970	154.1	69.2	101.4	82.9	95.4
58	Russian wildrye	1970	51.0	85.6	115.5	104.7	119.5
10	Russian wildrye	1971	66.4	72.9	105.3	79.4	110.4
12	Russian wildrye	1974	206.3	75.9	105.9	86.2	96.7
14	Russian wildrye	1974	105.3	75.0	108.3	85.1	95.2
65	Russian wildrye	1974	168.2	84.2	112.6	93.4	110.9
29	Russian wildrye	1975	155.7	74.7	105.8	93.8	113.7

[1]Not used in regression analysis.

Table 3. **Radar backscatter intensities for fields containing native range, Russian wildrye and crested wheatgrass from May and August C-band airborne radar images and for 2 modes, nadir and narrow swath.**

	Date			
	May		August	
Vegetation	Narrow	Nadir	Narrow	Nadir
	Digital number			
Native range	96.9	70.1	93.2	78.1
Crested wheatgrass	103.8	75.4	107.0	89.9
Russian wildrye	109.7	78.8	110.5	90.6

each of the 4 images. The airborne radar image did not cover all of fields 1-11, 68 and 71-74 shown in Figure 1 and thus they were excluded from the analysis. The fields were summarised according to species to which they had been seeded or date of seeding and the digital numbers compared with several fields of native range.

Effects of plant community

Radar digital numbers were extracted for each plot from a study established in 1954 to evaluate 3 methods of grazing on 3 vegetation types, native range, Russian wildrye and crested wheatgrass (Smoliak, 1968). The study had 3 replications for a total of 27 plots. The grazing systems were (i) season-long over a 6 month period, (ii) free choice, in which the animals could choose Russian wildrye, crested wheatgrass or native range, and (iii) rotation, in which the 3 vegetation types were fenced and grazed in rotation. In the rotation, crested wheatgrass was grazed in the spring for about 2 months, native range during the summer for about 1.5 months and Russian wildrye in the fall for 2.5 months. Data were subjected to analyses of variance.

Effect of soil and vegetation characteristics

Radar digital numbers from each of the 4 images at each of the ground-truth sample sites were extracted. The extracted data were subjected to a series of correlation analyses to determine the influence of vegetation and soil factors on radar backscatter.

Ground Data

Ground information, including 35 mm photographs, was collected at each of 19 sites, designated by the solid diamonds in Figure 1, on the same days as the airborne radar flights. The sites, which were approximately 4 ha, were selected to represent the range of different soil and vegetation found on the substation.

The percentage vegetation cover represented by 13 principal plant species was estimated. The species were grouped into native grasses (needle-and-thread, western wheatgrass, blue grama, Junegrass, and Sandberg's bluegrass), tame grasses (Russian wildrye and crested wheatgrass), sedges, palatable forbs (winterfat), unpalatable forbs (pasture sage) and other species (cactus, wild rose and wild onion). The value recorded for each species was an estimate of its percent ground cover.

At each site, five 0.25 m^2 samples were clipped and sealed in a plastic bag for dry biomass determination. Samples were weighed and oven-dried at 70° C to constant weight. Moisture content of the canopy was calculated from the wet and dry weights.

Soil moisture was measured at each site with a Trase (Soil Moisture Equipment Corp., Santa Barbara, CA) time domain reflectometry instrument developed on the principles described by Topp et al. (1980). In this study, 15-cm probes were used.

On 9 March 1992 and 22 June 1992 surface roughness of selected fields was measured using a truck-mounted device consisting of a small pneumatic wheel (11-cm radius) on a 75 cm arm mounted on a frame. As the truck moved across the site and the wheel moved vertically with the micro-terrain, the displacement was measured by a potentiometer. A linear relationship existed between potentiometer voltage and displacement height of the wheel. About 200 measurements were taken and the mean displacement height and the root mean square (rms) height calculated for each site.

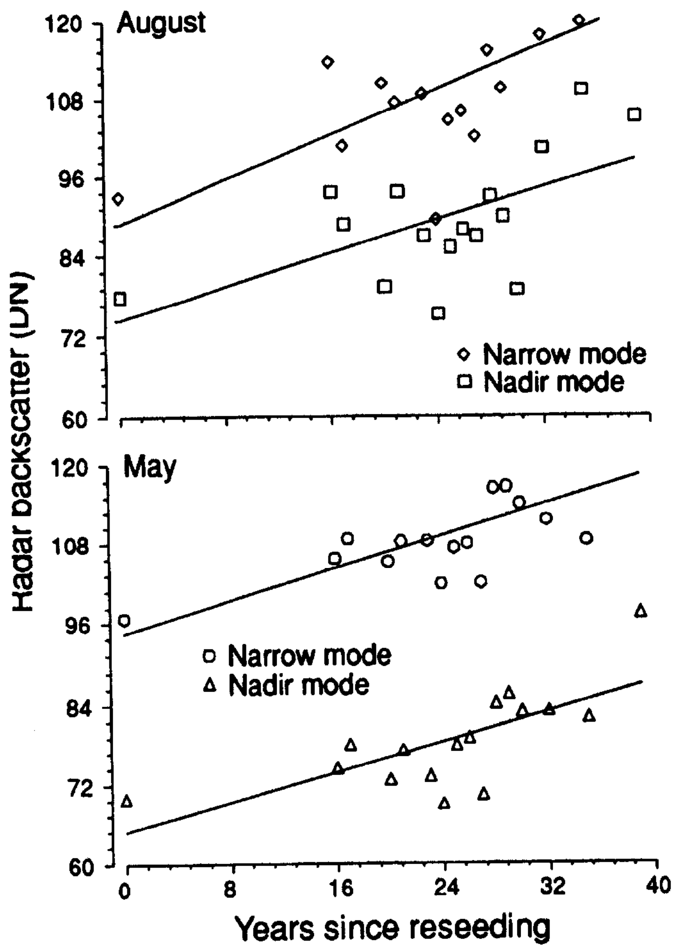

Fig. 2. The relationship between C-band HH radar backscatter and years since seeding to Russian wildrye (DN = 94.40+0.61*years r^2 = 0.52 for May narrow mode, DN = 64.79+57*years r^2 = 0.49 for May nadir mode, DN = 88.77 + 0.85*years r^2 = 0.49 for August nadir mode, DN = 74.37 + 0.62*years r^2 = 0.34 for August narrow mode).

Results and Discussion

In this study we concentrated on vegetation differences of fields and paddocks uniform in elevation and soil. The year and species of seeding, the area and radar digital number are shown in Table 2. On 24 May 1991, average soil moisture content was higher (15%) than on 1 August (8%). The first airborne radar flight was scheduled to coincide with maximum live vegetation and the second flight with the cessation of growth. However, 1991 was a wet year and there was still some green vegetation on 1 August. There was considerably more senesced vegetation than in May.

Effects of seeding

Summarizing radar digital number according to vegetation allowed comparisons of the radar backscatter from a total of 49 fields (Table 2). Russian wildrye had consistently higher digital number than native range (Table 3). The digital numbers for crested wheatgrass were intermediate between native range and Russian wildrye in the May images and similar to those for Russian wildrye in the August images.

Thirty-six fields were seeded between 1928 and 1975 and radar backscatter increased with time elapsed since seeding for the 2 SAR

Table 4. Analysis of variance using radar digital number extracted from a former grazing experiment containing 3 grazing rotations and 3 vegetation types replicated 3 times showing mean squares as well as root mean square errors (r.m.s.e.) and coefficients of variation (c.v. in percent).

		Mean Square			
		May		August	
Source of variation	Degrees of freedom	Nadir	Narrow	Nadir	Narrow
Replication	2	85.10**	129.32**	9.24	289.75**
Rotation (R)	2	10.79	36.80**	25.30	23.80
Vegetation (V)	2	37.40**	63.70**	266.97**	74.10**
R x V	4	2.43	3.10	4.00	12.09
Error	16	3.85	5.95	10.50	19.86
c.v.		3.27	2.44	3.83	4.33
r.m.s.e.		2.88	2.44	3.24	4.46

**$P<0.05$.

dates and modes (Table 2). However, for crested wheatgrass this relationship was not statistically significant ($P>0.05$). The variability in the digital number of crested wheatgrass with year from seeding may be due, in part, to some fields being located in apparently saline areas and giving a radar backscatter that responded to a modified dielectric constant. The crested wheatgrass field with the highest digital number (53) had a shrub windbreak along the western border of the field which would have contributed to the elevated backscatter. In contrast to crested wheatgrass, at both dates and in both swath modes, a significant positive relationship was found between the radar digital number of Russian wildrye fields and years since seeding (Figure 2). The expectation was that the seeded fields would revert back to native range after a number of years and that the radar backscatter would, therefore, return to values similar to those for native range. Visual observation indicated that native species, such as blue grama, had not recolonized fields except in isolated patches where establishment of seeded species may have failed. However, crested wheatgrass was able to colonize areas between the original rows therefore creating a more uniform microtopography. The differential in radar backscatter observed between crested wheatgrass and native range probably reflects the greater above-ground biomass production by the seeded species.

Preliminary surface roughness measurements revealed a weak positive relationship between radar backscatter and root mean square height. The ground measurements were taken in the year following image acquisition and although it is unlikely that surface roughness changed substantially during this time, further study is required to determine the extent of the seeding-induced erosion phenomenon and whether current revegetation recommendations are appropriate for the mixed prairie.

The steadily increasing radar backscatter with time since seeding suggests that revegetation is not the only factor altering the landscape. Examination of the Russian wildrye fields showed that, over the years, the soil between the rows has eroded leaving the crowns of the plants slightly elevated. In contrast, the surface in native range areas is uniformly smooth, with club moss and other species providing almost complete ground cover. Compared with Russian wildrye, crested wheatgrass fields also appear smoother.

Effect of plant community

The grazing experiment ended in 1974 and the fences separating plots were removed in 1977 but the experiment and its associated treatments were still apparent in the various airborne radar images, especially in the August nadir mode (Figure 3). The radar digital numbers for each of the 27 plots were extracted and subjected to analyses of variance (ANOVA). The ANOVA results for each of the dates and modes were essentially the same (Table 4). In all 4 ANOVA, digital number significantly differed with vegetation. Radar backscatter from Russian wildrye was higher than that for native range or crested wheatgrass (Table 5). The backscatter for crested wheatgrass was similar to that for native range in the narrow swath but less than and greater than native range in the May and August nadir mode, respectively. Although visually there was an obvious transition from native range to crested wheatgrass, it was not evident in the digital number extracted from all images. In the areas seeded to Russian wildrye, the soil between the rows was badly eroded; consequently these plots have a rougher surface topography and had higher backscatter than those in native range.

Only in the May narrow mode was any difference detected between the 3 rotation treatments. The rms error and the coefficients of variation of the ANOVA were low suggesting good capabilities for discriminating differences.

Effect of soil and vegetation characteristics

The ground data from each date (Tables 6 and 7) were compared to the radar digital number extracted from the corresponding radar image in the narrow and nadir swath modes. With respect to the May data, radar digital number from the narrow swath mode image was positively related to the moisture content of the plant canopy (r=0.612). The observation that radar backscatter increased with increasing water content of the canopy is consistent with the findings of Brakke et al. (1981) and Major et al. (1991a). In the nadir swath mode, radar digital number was positively and significantly related to gravimetric soil moisture (r=0.767). The influence of soil moisture on radar backscatter has been reported previously (Brisco et al., 1991). In both modes greater correlations would probably have existed between a combination of volumetric soil and canopy moisture and radar digital number (Major et al., 1993), but in the absence of height data canopy moisture could only be calculated on a per area basis.

In the May narrow swath mode, radar digital number increased as the percentage of needle-and-thread and blue grama increased (r=-0.63 and r=-0.64, respectively). Thus, backscatter decreased with an increase in the dominant native species which is consistent with the lower backscatter for the native range discussed previously. Conversely, as Sandberg's bluegrass, forbs and shrubs increased so did radar digital number in the May narrow swath mode (r=0.66, 0.78 and 0.56, respectively). In the nadir mode only the amount of western wheatgrass present influenced radar digital number (r=0.66). Analysis of the data for August showed that as ground cover decreased radar digital number increased (r=-0.56 and -0.52 respectively for the narrow and nadir modes). No significant relationship was found between soil moisture and radar backscatter in August.

In summary, the ground data indicated that in May, but not August, radar backscatter in the narrow mode was related to plant characteris-

Table 5. Radar digital numbers from 4 images combining May and August dates and narrow swath and nadir modes, for a grazing experiment utilizing 3 grazing systems and 3 vegetation types at Onefour AB.

Vegetation Date/Mode	Native range	Crested wheatgrass	Russian wildrye
	Digital number		
May			
Nadir	82.4a	79.0b	82.8a
Narrow	99.3b	97.5b	102.8a
August			
Nadir	79.6c	83.3b	90.3a
Narrow	100.7b	101.7b	106.1a

Table 6. Vegetation composition of major species (%), biomass and moisture, soil moisture and ground cover at the 19 ground sites on 24 May 1991.

Site	Field	Plant dry weight	Plant moisture	Soil moisture	NT	WG	BG	JG	SB	SD	PS	RW	CW	Ground cover
		(g/m^2)	(g/m^2)	(%)	% composition									(%)
1	13	76.56	57.92	16.00	8	6	2	1	1	13	0	0	90.6	-
2	12	82.34	92.32	12.78	1	2	1	1	10	3	19	64	0	62.0
3	2	50.56	43.92	.	56	1	6	2	3	6	3	0	0	71.0
4	2	20.00	16.88	.	23	4	6	5	0	2	2	0	0	56.0
5	2	34.26	26.80	.	20	1	3	6	0	5	4	0	0	49.0
6	2	19.19	23.04	19.82	14	11	8	5	0	3	4	1	0	63.0
7	2	22.33	22.88	21.30	16	13	6	4	0	3	9	0	0	68.0
8	68	102.70	90.30	28.89	0	86	0	0	5	0	0	0	0	50.0
9	68	54.84	49.76	12.44	79	5	2	1	2	0	5	0	0	87.0
10	68	79.64	40.56	11.77	79	1	2	5	0	2	6	0	0	74.6
11	28	47.68	41.20	15.00	59	3	4	3	0	2	3	0	0	65.0
12	29	58.16	97.12	12.00	16	3	1	6	3	3	14	24	0	50.0
13	29	76.10	106.80	16.00	2	53	1	2	0	4	3	18	0	68.0
14	39	93.24	105.36	15.47	0	56	0	0	27	0	0	0	0	57.0
15	42	109.96	87.92	21.28	0	2	0	0	0	0	22	76	0	53.0
16	49	107.56	106.48	13.81	36	3	0	1	0	1	5	41	9	55.0
17	23	63.92	56.40	10.32	22	18	17	2	0	18	3	0	0	87.0
18	26	298.36	186.72	—	4	8	0	6	0	4	9	11	48	83.0
19	73	78.84	60.00	11.46	27	14	15	14	3	13	9	0	0	87.0

NT = needle-and-thread, WG = western wheatgrass, BG = blue grama, JG = Junegrass, SB = Sandberg's bluegrass, SD = sedges, PS = pasture sage, RW = Russian wildrye, CW = crested wheatgrass.

tics while that in the nadir mode was related to soil characteristics. The date and mode of acquisition therefore influences the type of information acquired on an airborne radar image.

Conclusions

This study demonstrated that radar backscatter was influenced by rangeland vegetation. Radar was valuable in differentiating vegetation types, the extent of the differentiation being dependent upon the timing of and the mode of data acquisition. Data acquired in May were more readily related to measurable ground features. The information acquired in the narrow mode primarily reflected plant characteristics while that obtained in the nadir mode primarily reflected soil charac-

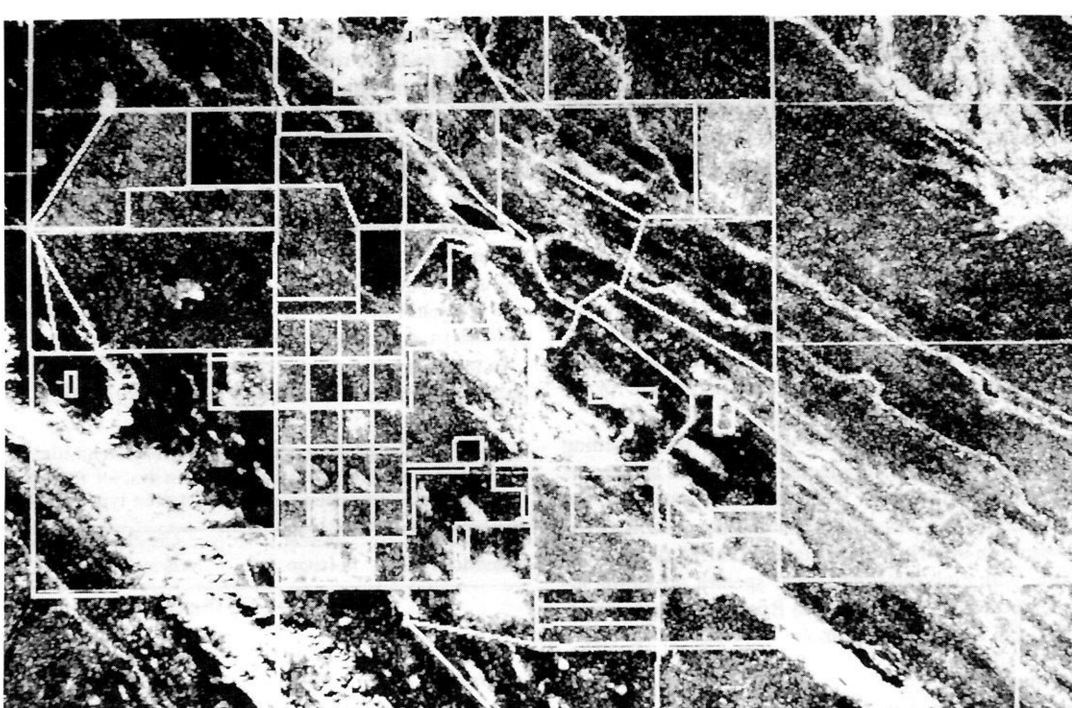

Fig. 3. A C-HH, nadir mode airborne synthetic aperture radar image of the Agriculture Canada Substation at Onefour, AB acquired on 1 Aug. 1991.

Table 7. Vegetation composition of major species (%), biomass and moisture, soil moisture and ground cover at the19 ground sites on 1 August 1991.

Site	Field	Plant dry weight	Plant moisture	Soil moisture	NT	WG	BG	JG	SB	SD	PS	RW	CW	Ground cover
		(g/m^2)	(g/m^2)	(%)	% composition									(%)
1	13	50.44	28.84	4.62	59	1	3	2	0	2	33	0	0	93.0
2	12	74.88	27.44	7.02	3	3	0	2	0	0	26	57	9	50.0
3	2	141.50	68.49	9.10	36	2	11	13	0	6	25	0	0	25.0
4	2	47.58	25.93	7.50	25	3	21	15	0	5	20	0	0	17.0
5	2	87.75	37.52	9.64	27	13	10	11	0	4	18	0	0	25.0
6	2	58.28	46.59	10.92	36	9	13	12	0	5	25	1	0	5.0
7	2	92.74	55.09	8.00	37	12	10	7	0	4	25	0	0	2.0
8	68	106.56	78.79	6.34	0	85	0	0	4	0	0	0	0	50.0
9	68	57.27	26.80	6.40	62	1	2	4	0	2	15	0	0	90.0
10	68	47.40	25.39	6.04	63	1	5	2	1	1	10	0	0	86.0
11	28	64.12	39.64	9.62	6	11	43	2	0	2	6	0	0	67.0
12	29	80.55	40.56	7.76	18	9	11	1	2	2	7	0	0	44.0
13	29	73.41	37.62	10.08	0	14	1	2	4	5	7	25	0	46.0
14	39	82.68	33.80	.	23	23	1	0	0	0	40	1	0	51.0
15	42	145.12	43.35	6.98	3	2	1	0	0	0	11	83	0	72.0
16	49	87.34	42.65	11.10	0	0	0	0	0	0	1	88	9	35.0
17	27	111.54	49.73	5.02	66	7	14	2	0	10	1	0	0	78.0
18	26	53.92	20.87	5.70	29	5	0	4	0	1	5	0	56	82.0
19	73	150.49	59.10	4.80	40	9	28	0	0	28	1	0	0	74.0

NT = needle-and-thread, WG = western wheatgrass, BG = blue grama, JG = Junegrass, SB = Sandberg's bluegrass, SD = sedges, PS = pasture sage, RW = Russian wildrye, CW = crested wheatgrass.

teristics. The striking relationship between radar backscatter and the number of years since seeding in the case of Russian wildrye requires further study to determine when and if this pattern reverses. If surface conditions are still changing after more than 60 years, range managers should be aware of this. The detection of year to year differences in range condition are unlikely because changes in range condition occur over a long period.

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