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Spectral Reflectance Measurements of Alfalfa under Sheep Grazing

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ABSTRACT

Lamb grazing experiments conducted on alfalfa (*Medicago sativa* L.) fields require numerous measurements of phytomass in order to identify optimum conditions for lamb weight gain. Our objective was to test the ability of spectral reflectance measurements with a portable hand-held radiometer to predict alfalfa phytomass. We used vegetative indices consisting of linear combinations of the near infrared (*NIR*) and red wavelength intervals, such as the *NIR/Red* ratio and normalized difference (*ND*). Reflectance measurements were taken during two grazing trials where alfalfa phytomass ranged from 200 g m^{-2} initially to negligible phytomass after 15 d of intensive grazing. A portion of the alfalfa was desiccated due to frost damage during the second trial. The *ND* and *NIR/Red* were well correlated with alfalfa phytomass (r = 0.87–0.97). Measurements taken at solar zenith angles (57 and 69°) were found to produce similar *ND*/phytomass regression coefficients. The desiccated alfalfa increased red reflectance, which consequently lowered the *ND* and *NIR/Red* values. The *ND* was preferable to *NIR/Red* because it was more sensitive to low phytomass levels that are characteristic of grazing studies. An *ND* of 0.55 identified a threshold phytomass level, below which continued grazing caused a decrease in lamb weight gain. Handheld radiometric measurements are a quick, accurate, nondestructive means of estimating alfalfa phytomass in pasture grazing experiments.

In the western USA, sheep (*Ovis aries* L.) are routinely transported from high mountain summer pasture to irrigated alfalfa fields in the lower valleys to graze during the winter. Late-born lambs weighing 30 to 40 kg graze for up to 12 wk until they weigh 55 kg, and then are shipped to market. Daily weight gain in these animals during this time is of paramount importance because grazing fees are assessed for each lamb on a daily basis. Sheep weight gain depends on the daily quality and quantity of the forage available. Presently, nutritional studies are underway to define optimum grazing strategies and alfalfa management practices based on available forage (Guerrero et al., 1989). Numerous field samples of alfalfa, which require extensive time and labor, are taken during pasturing experiments. Ground-based, remote sensing measurements could augment or even replace conventional forage sampling techniques. Remote measurements are rapid, nondestructive, and can save time and labor while extending the area which can reasonably be sampled.

The physical justification for remote assessment of plant phytomass originates from the differential scat-

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tering/absorption properties of vegetative canopies and underlying soils. Dense, healthy, green foliage has very low reflectance in the visible portion of the solar spectrum (especially the red region) because energy in these wavelengths is captured by chlorophyll (Jackson et al., 1980). In the *NIR* wave band, vigorous vegetation reflects more than half the solar irradiance. In contrast, reflectance properties of most agricultural soils are quite different from plants and vary with soil type and surface moisture conditions (Pinter et al., 1987). In general, reflectance of red light from soil can be as much as ten times greater than that from plants, while *NIR* reflectance from many pasture soils is only half that from plants. Thus the relative amounts of vegetation and exposed soil in a composite canopy can be inferred from spectral indices derived from combinations of *Red* and *NIR* reflectances.

Commonly used vegetative indices include the ratio of *NIR* to red reflectance (*NIR*/*Red*) and the *ND* between the two bands where *ND* = (*NIR*-*Red*)/(*NIR* + *Red*). Other linear combinations of the bands exist which produce specific information about a target of interest. An important advantage with *NIR*/*Red* and *ND* indices is their ability to preserve much information on plant phytomass despite complexities introduced by variable cloud cover during field measurements (Pinter et al., 1987).

Earlier investigations have demonstrated the usefulness of vegetative indices for estimating agronomic characteristics of growing alfalfa (Jackson et al., 1980; Kirchner et al., 1982; Pinter et al., 1987) and mixed-species hayfields (Bédard and Lapointe, 1987; Aase et al., 1987). Little information, however, exists on their applicability under grazing conditions where the phytomass is rapidly decreasing in time. Furthermore, sheep consume forage by first stripping off the more palatable and nutritious leaflets, and then feeding on the stems and crowns (Guerrero et al., 1989). This selective-grazing preference soon produces a canopy dominated by stem material. The leaf area index will be less per unit phytomass than what is usually found in growing canopies, where most remote sensing experiments have been conducted.

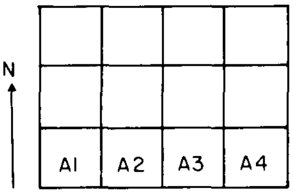
Our objectives were threefold:

1. To evaluate the utility of the *NIR*/*Red* and *ND* indices for estimating alfalfa phytomass for sheep grazing conditions,
2. To compare two solar illumination angles for sensing low phytomass conditions of grazed pastures, and
3. To appraise the vegetative indices' ability to identify pasture conditions of suboptimal sheep weight gain.

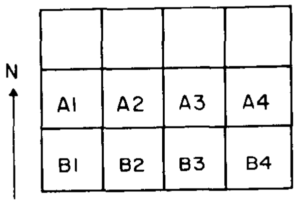
MATERIALS AND METHODS

We designed our experiment around lamb-grazing trials in order to test the technology where it will be put to use—by researchers in lamb-grazing experiments. Our approach was to use linear and transform-linear regression of the vegetative indices against alfalfa phytomass during grazing. Correlation analysis was conducted to compare the influence of plant components (leaf, stem, and desiccated forage) on the indices at two angles. The lamb-grazing experiments provided us with a large range of alfalfa phytomass with which to formulate phytomass regression equations. The experiments also furnished us with measures of stocking rate and lamb weight gain. We used stocking rate to illustrate the response of the vegetative indices to declining phytomass pasture conditions. We employed lamb weight gain to portray how remotely sensed indices offer an approximate indication of lamb weight gain, although weight gain depends on numerous other factors beyond the scope of this report, e.g., climate, genetics, and initial animal weight.

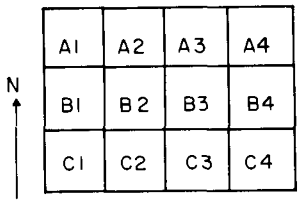
The spectral reflectance measurements were conducted coincident with two lamb grazing trials at the Imperial Valley Agricultural Experiment Station, El Centro, Ca (32°49′ N, 115°25′30″ W). Trial I took place from 26 Nov. to 26 Dec. 1986 and Trial II from 5 Jan. to 7 Feb. 1987. The parallel purpose of these trials, to be reported elsewhere, was to relate lamb weight gain to available forage, thereby providing guidelines for herd managers to optimize lamb weight gain. Design of the lamb grazing experiments is depicted in Fig. 1. Fenced grazing paddocks (0.04 ha) were located within a



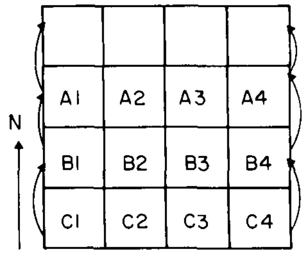
A grazers start grazing cycle.



On day 5 *A* grazers move north. *B* grazers move onto paddocks left by *A* grazers.



On day 10 *A* grazers move north. *B* grazers move onto paddocks left by *A* grazers. *C* grazers move onto paddocks left by *B* grazers.



Every 5 days the whole sequence moves one paddock.

Fig. 1. Design of grazing experiment of available forage treatments on lamb weight gain, which was coincident to the spectral reflectance experiments.

field of established alfalfa cultivar CUF 101, which is nondormant in winter. Each paddock contained four lambs and was replicated four times. Lambs were moved every 5 d according to three treatments (Fig. 1). The *A* grazers moved to fresh paddocks, the *B* grazers moved to the paddocks abandoned by the *A* grazers, and *C* grazers moved to paddocks abandoned by the *B* grazers.

Sheep characteristically graze by first stripping off the alfalfa leaves, then later feeding on the stems and crowns (Guerrero et al., 1989). Grazers *A*, *B*, and *C* roughly corresponded to leaf grazers, stem-plus-leaf grazers, and stem-plus-crown grazers, respectively. Each paddock was grazed 15 d total, by which time essentially all of the alfalfa was consumed. Lambs were weighed at the beginning and end of each 30 d trial to obtain a value of average daily weight gain. It is important to note that sheep weight gain is influenced by several factors including climate, initial lamb size, and health. Because these variables are hard to control in field experiments, weight gain can vary greatly between trials. More critical to grazing management is the threshold amount of available forage below which the animals experience a decline in rate of weight gain.

Forage Sampling

Above-ground alfalfa phytomass was sampled in both ungrazed and grazed paddocks on Days 2, 4, 7, 9, 12, and 14 of the grazing rotation. Four subsamples were collected in each paddock from inside a 0.25-m^2 ring. Samples were taken to the lab where they were separated into groups of stems and leaves, then dried at 50 °C for 48 h and weighed. In Trial II, the alfalfa was frost damaged and water stressed, such that some plants desiccated and dulled in color. To quantify the effect of these plants on reflectance measurements, a third category of desiccated alfalfa was added to the separation procedure.

Radiometric Observations

Crop canopy radiance was measured with an Exotech Model 100A (Exotech, Inc., Gaithersburg, MD) portable radiometer[1] that was equipped with four spectral bandpass filters similar to Multispectral Scanner on Landsat 5, including the *Red* (0.6–0.7 μm) and *NIR* (0.8–1.1 μm) wave bands. The radiometer, mounted at the end of a hand-supported monopod, was held at a height of approximately 1.50 m above the soil surface. The radiometer always viewed the target in a nadir direction. The 15° field-of-view lenses afforded a target size of approximately 0.12 m^2 at the soil surface. The operator obtained 10 readings by swinging the monopod slowly in a 2-m-long arc across the same area where the phytomass samples were to be collected. The average of the 10 readings was considered a single composite measurement of canopy radiance, and was recorded along with the measurement time into a portable data logger (Omnidata Polycorder Model 516C, Omnidata International, Inc., Logan, UT) and later transferred to a microcomputer for processing. Four of these composite readings were taken from each paddock in approximately 1 min, requiring a total of 20 min for all 16 paddocks.

Reflectances were computed by dividing crop canopy radiances by the radiance measured over a reference reflectance panel that was calibrated according to Jackson et al. (1987). The panel was constructed to approximate the reflectance characteristics of a perfectly diffuse surface. Before and after the field measurement routine, radiometer readings were taken over the panel, so that reference radiance at the time of canopy measurements was inferred from a time-based linear interpolation of the two panel measurements. Alfalfa reflectance data were averaged for each paddock, and then used to compute *NIR/Red* and *ND*.

Reflectances were measured between 1030 h and 1130 h (PST) at a time period corresponding to a solar zenith angle of 57 ± 1°. Because the amount of leaf area was very low at high stocking rates, and being cognizant of the ability of larger zenith angles to increase the sensitivity of vegetative indices for low leaf area in wheat (Pinter et al., 1983), we also acquired a set of reflectance measurements once per week at a solar zenith angle of 69 ± 2°.

Statistics

Correlation analysis was performed on the phytomass component (stem, leaf, and desiccated). Data from each of the trials and measurement angles were regressed against the leaf-plus stem components of alfalfa phytomass. For each data set, linear and logarithmic regressions were compared for best fit by looking at plots of residuals, and observing any systematic bias. Tests were made for statistical congruence of regressions between Trial I and II (Neter and Wasserman, 1974, p. 161), to see if a single regression equation was valid over both trials.

RESULTS AND DISCUSSION

The selective grazing habits of lambs are shown in Fig. 2 where alfalfa phytomass components decreased with increasing stocking rate. In the initial stages of stocking rate, leaf mass decreased substantially while stem mass declined only slightly. After 500 lamb days ha^{-1} the majority of the remaining phytomass was stems. Desiccated phytomass decreased evenly over the entire range of stocking rate, indicating that the sheep treated it as they did alfalfa generally and were not adverse to feeding on desiccated leaves. The lambs of Trial II devoured alfalfa faster than their counter-

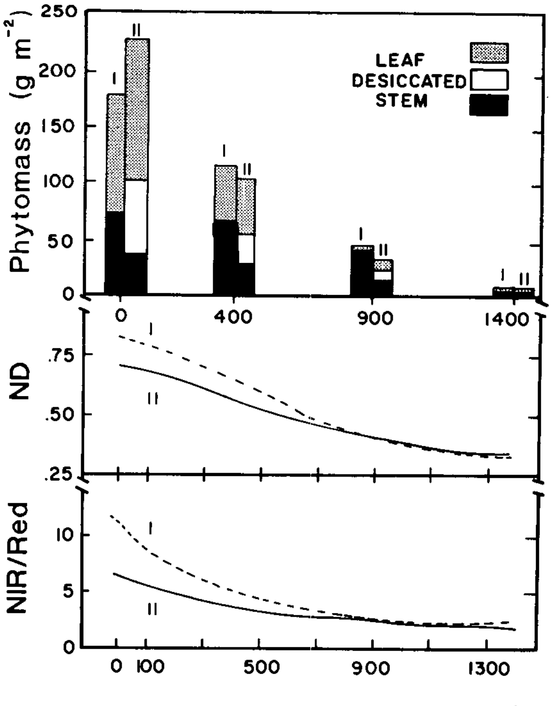


Fig. 2. Alfalfa phytomass components, normalized difference, and *NIR/Red* responses to stocking rate for Trials I and II.

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[1] Mention of trade name does not imply USDA endorsement.

parts in Trial I, and also gained more weight. This may have been due to higher initial weight (45 vs. 40 kg). Another possible reason is that the lambs of Trial I had less recuperative time after transport to the experimental site from the mountain pastures. Differential forage consumption between trials and its varied effect on alfalfa phytomass underscores the necessity of pasture monitoring.

The *NIR*/*Red* and *ND* indices likewise decreased with increasing stocking rate (Fig. 2). Both *NIR*/*Red* and *ND* were plotted as a smooth curve connecting seven points that were averages of 48 observations at each of seven stocking rates for each trial. If we observe the *NIR*/*Red* and *ND* over the range of low stocking rate (Fig. 2, 0–200 head d ha^{-1}), we find the *NIR*/*Red* to fluctuate more than *ND*. But as stocking rate increases (Fig. 2, 300–900 head d ha^{-1}), the *ND* fluctuates more than *NIR*/*Red*. Hence, the *NIR*/*Red* was more sensitive than *ND* to changes in phytomass at low stocking rate (high phytomass), while *ND* was more sensitive than *NIR*/*Red* at high stocking rate (lower phytomass). Low phytomass levels are dominated by the stem component, which strongly influences the *NIR* reflectance but effects the *Red* reflectance only slightly. Thus, during low phytomass conditions, the vegetative indices are influenced by small changes in the *NIR*. The *ND* is more sensitive than *NIR*/*Red* to phytomass changes because it amplifies the *NIR* component in its calculations.

Both *ND* and *NIR*/*Red* showed markedly higher correlations with leaf than stem phytomass (Table 1). The *NIR*/*Red* ratio correlated better with the leaf than leaf-plus-stem grouping, which further demonstrated the ratio's poor response at lower levels of leaf mass. Conversely, *ND* correlated slightly better with leaf-plus-stem than leafy phytomass alone.

Desiccated phytomass was not well correlated with either *ND* or *NIR*/*Red*. Leaf-plus-stem groupings which included desiccated phytomass did not correlate as well with the vegetative indices as did those groupings which excluded desiccated phytomass. These results are to be expected because desiccated plants do not absorb red radiation as well as healthy plants. Subsequently, desiccated alfalfa was excluded in phytomass regressions.

Regression models were good predictors of alfalfa phytomass with r^2 values greater than 80% (Table 2). Values for both vegetative indices were smaller in Trial II although alfalfa density was higher. The discrepancy in the vegetative index response between the trials was attributed to desiccated alfalfa of Trial II which altered the canopy reflection. *Red* reflectance was higher for Trial II than I, while *NIR* reflectance was nearly identical for both trials (data not shown). The higher *Red* reflectances were caused by lower absorption by desiccated plants. This is consistent with the observation (Tucker, 1978) that higher proportions of desiccated (brown) grass increased solar reflectance for most wavelength intervals. When both *Red* and *NIR* intervals were combined into vegetative indices,

Table 1. Correlation coefficients of vegetative indices with alfalfa phytomass components and stocking rate at different view angles.

		NIR/*Red*		*ND*	
	Trial	57°	69°	57°	69°
		r			
Leaf mass	I	0.94	0.96	0.93	0.93
	II	0.95	0.96	0.89	0.83
Stem mass	I	0.64	0.66	0.81	0.86
	II	0.73	0.74	0.74	0.76
Desiccated†	II	0.69	0.67	0.68	0.60
Leaf + stem	I	0.88	0.89	0.95	0.97
	II	0.94	0.92	0.90	0.87
Leaf + stem + desiccated	II	0.92	0.88	0.89	0.82
		n			
Sample size	I	(117)	(39)	(117)	(39)
	II	(91)	(39)	(91)	(39)

† Not measured separately from total phytomass in Trial I.

Table 2. Regression coefficients for alfalfa phytomass vs. vegetative indices. Linear model, phytomass $= a + b$ (Veg Index). Logarithmic model, phytomass $= a + b$ [ln(Veg Index)]. Only the data of *ND* 69° were not significantly different ($\alpha = 0.05$) over both trials.

Veg. Index	Model	Solar zenith	Trial	*n*	r^2	*a*	*b*	S_{yx}†
		degree			%	g m^{-2}		g m^{-2}
NIR/*Red*	Linear	57	I	117	77	7.5	17.3	26.5
			II	91	88	−58.6	34.6	19.0
		69	I	39	80	−3.2	17.0	26.7
			II	39	93	−65.3	37.0	14.2
	Log	57	I	117	89	−36.2	91.9	18.7
			II	91	86	−84.8	126.9	20.7
		69	I	39	92	−50.0	93.8	16.5
			II	39	91	−84.7	127.7	15.8
ND	Linear	57	I	117	81	−79.0	284.4	23.9
			II	91	80	−119.7	360.8	24.4
		69	I	39	95	−97.7	313.9	13.3
			II	39	88	−116.3	355.0	18.7
			pooled	78	77	−98.6	322.0	29.1
	Log	57	I	117	81	177.3	154.2	24.0
			II	91	75	185.2	170.5	27.2
		69	I	39	93	183.0	165.6	15.9
			II	39	83	183.1	166.3	21.7
			pooled	78	75	185.5	165.6	30.3

† Standard error of y at a given x.

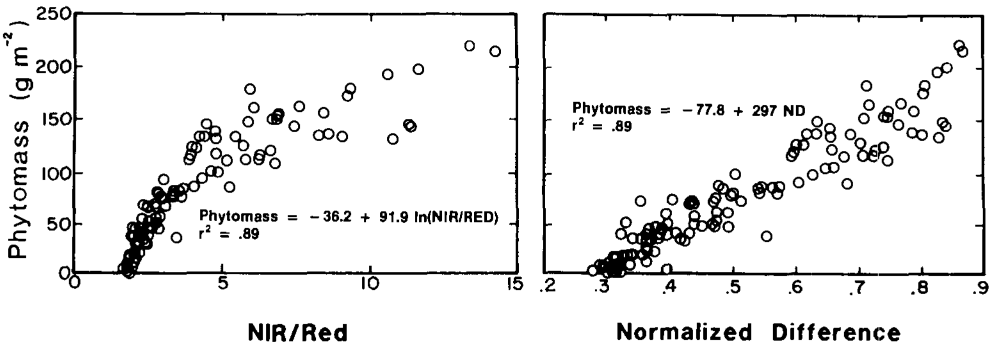

Fig. 3. Alfalfa phytomass vs. *NIR/Red* and normalized difference for Trial 1. The regression equations were logarithmic for *NIR/Red* and linear for the normalized difference. Each point represents one paddock.

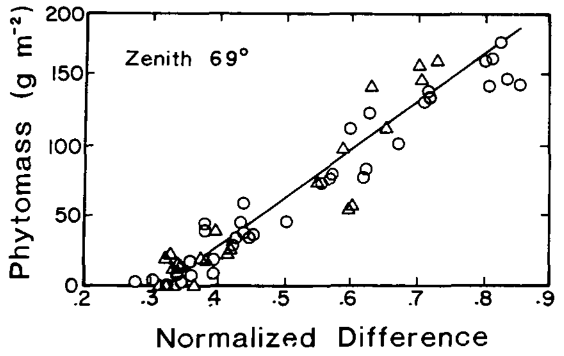

Fig. 4. Alfalfa phytomass vs. normalized difference for Trials I (○) and II (△) at 69° zenith angle. Each point represents one paddock.

the net effect of higher *Red* reflectance was a decrease in the value of the vegetative index for canopies with desiccated plants.

In addition to the overall decrease in vegetative indices caused by desiccated plants, there is also a linearizing effect on the *NIR/Red* phytomass relationship, that was first noticed by Tucker (1979). This accounts for the different shape of our *NIR/Red* regression curve between the trials. The *NIR/Red* curve was best described as logarithmic for Trial I, but was linear for Trial II when desiccated plants were present (Fig. 3, Table 2).

Regressions for the other indices and angles also differed significantly between trials, except in the case of the *ND* measured at a 69° zenith angle (Table 2 and Fig. 4). The *ND* at this measurement angle was relatively insensitive to desiccated phytomass, and is recommended for such conditions. This means the data can be pooled over both trials and a single equation is adequate for phytomass prediction.

To reiterate, the *ND* index had a twofold advantage over *NIR/Red* for predicting alfalfa phytomass for grazing studies. First, the *NIR/Red* was not as sensitive as the *ND* to changes in phytomass at levels below 50 g m^{-2}, which is a critical range in grazing research. Second, the *ND*/phytomass calibration was linear over both trials, whereas the *NIR/Red* calibration was logarithmic for Trial I (Fig. 3). The linearity of our *ND*/phytomass relationship was at odds with Bédard and Lapointe (1987) who found logarithmic models better at predicting dry green biomass in mixed-species hayfields consisting of timothy (*Phleum pratense* L.), red clover (*Trifolium pratense* L.), alfalfa, and other uncultivated plants. The incongruence of the relationships may have resulted from different vegetation and climate, or from the changing solar zenith angle during the day in the Bédard and Lapointe (1987) study.

In cropping systems where growers use grazing to remove most of the above-ground alfalfa for weed control, phytomass often falls below levels necessary to achieve optimum lamb weight gain. Guerrero and Marble (1987), for example, have shown that weight gain declines rapidly once alfalfa phytomass decreases to 50 g m^{-2} and lambs actually lose weight when phytomass drops below 10 g m^{-2}. The ability to assess these threshold values using a nondestructive, remote sensing technique would confer considerable benefit on future research and management activities. For each of the trials, the data demonstrates a relation between the average rate of lamb weight gain and the corresponding average *ND* (Fig. 5) that is strikingly similar to plots of animal weight gain vs. available feed found by others (Petersen et al., 1965; Jones and Sandland, 1974), where animal weight gain remains constant after reaching a threshold value of available feed. The similarity of our curves with the classical relationship implies that animal weight gain responds to *ND* just as it responds to available feed. Furthermore, the inflection point where lamb weight gain levels off, occurred near *ND* = 0.55 for both trials. Such results are encouraging. They imply that spectral vegetation indices could be used indirectly as a surrogate for tedious phytomass sampling in research programs or directly as an additional management criterion for pasture stocking strategies. The fact that the two curves of Fig. 5 are not coincident is not surprising. The relationship between weight gain in lambs and alfalfa phytomass is very complex because of factors which independently influence sheep metabolism and the reflectance of alfalfa canopies, and both of these factors differed for the two grazing periods. [See Guerrero et al. (1989) for discussion of differences in lamb weight between trials.]

Throughout this report we have discussed vegetative indices from reflectance measurements, although those calculated from canopy radiance alone were equally well correlated with phytomass. These results are valuable from the practical standpoint of saving time. Calculating vegetative indices directly from radiance measurements eliminates reference panel readings and the processing of canopy radiance data to reflectance by computer. Hence, the user can obtain

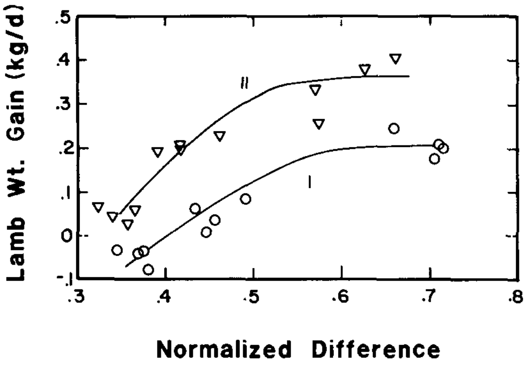

Fig. 5. Lamb weight gain vs. average normalized difference for trials I (○) and II (△). Each point represents one replication (four lambs) of a grazing treatment vs. the normalized difference of alfalfa grazed by the group over the entire trial.

immediate estimates of alfalfa in the field from the radiance vegetative indices. When using radiance-derived vegetative index estimates of phytomass in grazing trials, we recommend occasional plant sampling to guard against operator error or changing conditions where the phytomass regressions may vary. Caution should be used in extending these relationships outside of our experimental conditions of level, monospecies alfalfa pastures and cloudless days.

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