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ABSTRACT

A laboratory spectroradiometric method for the rapid determination of live/dead vegetation percentages from clipped grass samples has been developed and preliminarily tested. The method utilizes the red and photographic infrared reflectance or radiance differences between green vegetation and that of dead vegetation. Mixtures of green and dead material were found to have reflectances or radiances proportional to the mixture percentage. This method offers the possibility that rapid live/dead spectroradiometric determinations may replace the tedious band-sorting now generally in use for many situations.

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INTRODUCTION

Live/dead measurements of cut grass material have traditionally been made by hand, by detailed hand sorting usually aided by tweezers. The use of this method is tedious, time consuming, and does not endear one to your technicians. To date, however, there has not been any satisfactory alternative.

It has, no doubt, been apparent to several workers that the basis for these tedious separations is the color differences between live (green) and dead (brown) vegetation. The possibility that some automated method might replace the hand-method of sorting, at least in part, has probably cheered many workers in this endeavor.

Several pasture scientists have periodically suggested that some laboratory remote sensing method might be developed to automate these determinations. A very preliminary experiment was attempted in the laboratory of S. A. Grant and John Hodgson, Hill Farming Research Organization, Penicuik, Scotland in late summer 1976. The data from this was encouraging to the author but suffered from a sample size of n = 4. The author decided to repeat the experiment in a more vigorous way incorporating several changes in the experimental procedure(s) and using a much larger sample size.

INSTRUMENTATION

A simple hand-held device which was constructed and configured for estimating green biomass by measuring the reflected radiation in two wavelength bands was used for this experiment (Figure 1). The bands of 0.650-0.700 and 0.775-0.825 μm were used and were selected by placing a custom-built interference filter over each of two probes, respectively (Figure 2). The filter bandwidths were set as narrow as possible consistent with allowing enough radiant energy through to the silicon photodiode in each probe to give a sufficient noise-free output (Pearson et al., 1976).

Each probe has an ~24 viewing angle or a solid angle of ~0.15 sr. When held 40 cm above a surface, for example, each probe subtends a circular area with a diameter of ~20 cm.

The two filters were specifically chosen to be centered around 0.675 and 0.800 μm, respectively. The 0.650-0.700 μm filter is centered over the <u>in vivo</u> red spectral region of maximum chlorophyll absorption. Radiances in this wavelength region show an inverse trend as the (green) biomass (and hence the chlorophyll) increases.

The 0.775-0.825 μm filter was selected to straddle the 0.800 μm midpoint and is situated in a region of the spectrum where green vegetation has characteristically high levels of reflectance. Reflectance or radiance in the 0.775-0.825 μm region exhibits a direct trend as the green biomass increases.

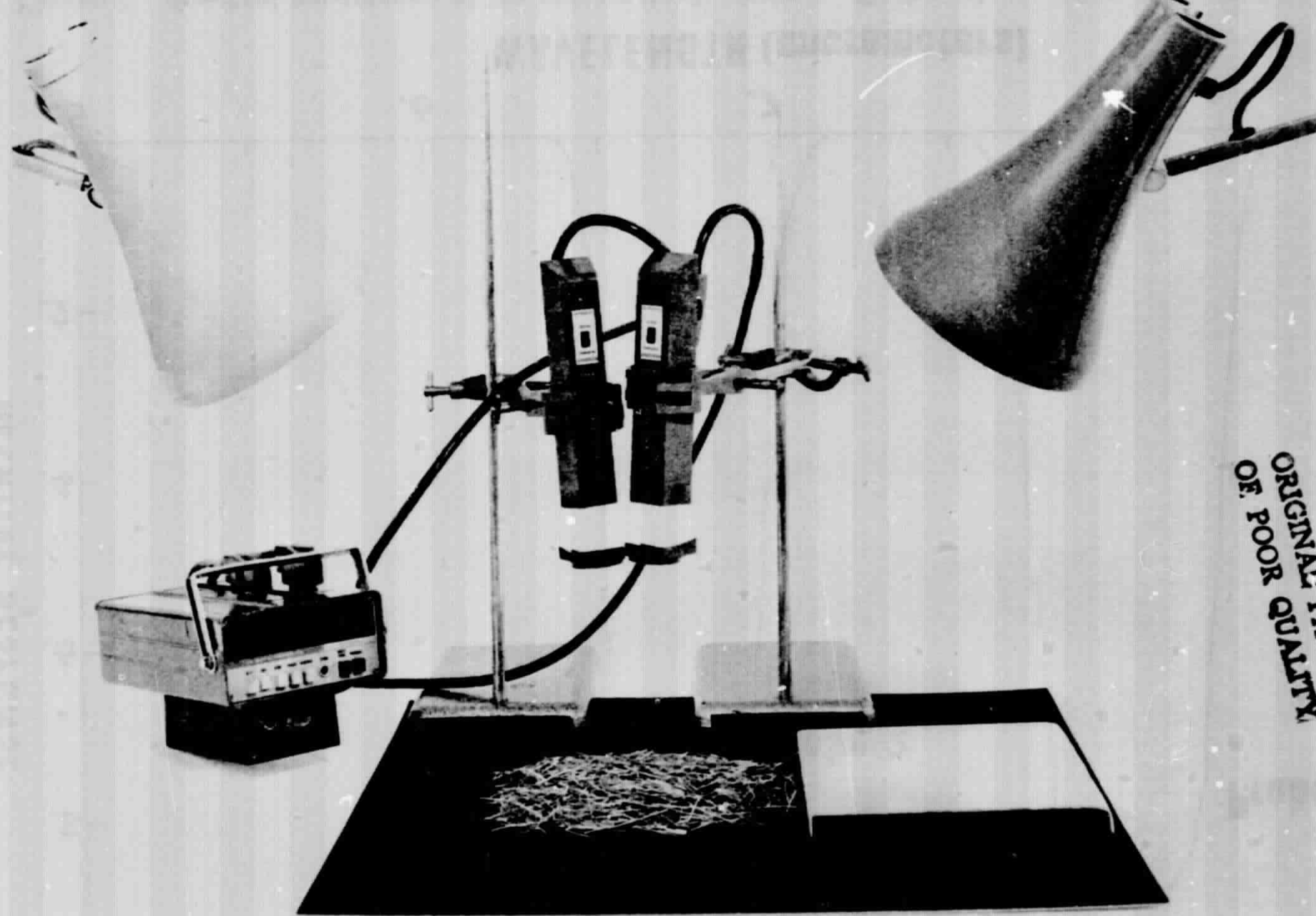


Figure 1. Hand-held digital radiometer used as a live/dead estimation device. The instrument consists of a digital radiometer that measures radiances from laboratory samples through two filtered probes.

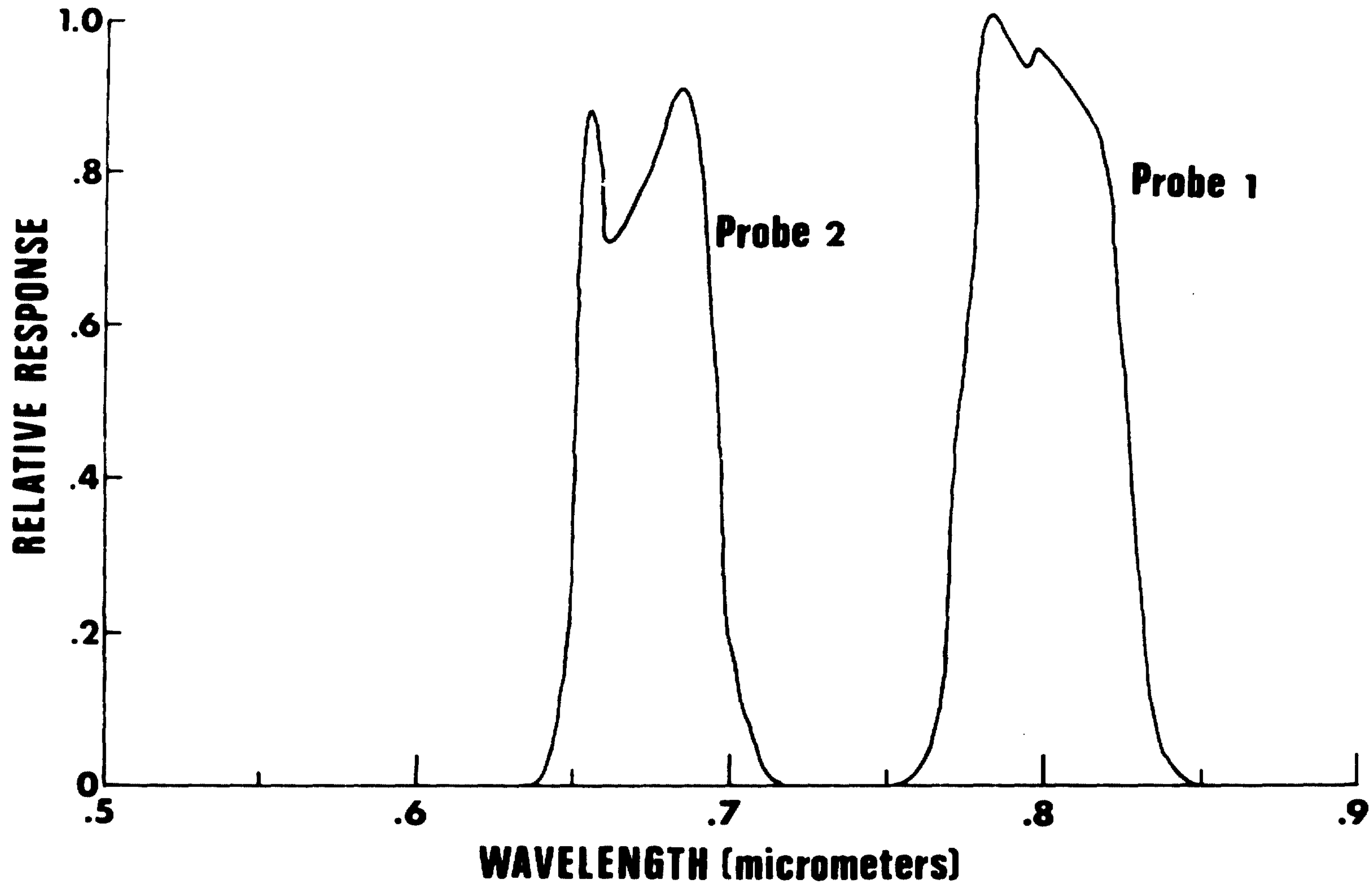


Figure 2. Spectral acceptance of the radiometer's probes. Each probe consists of a silicon photodiode that views the vegetated plot through a custom-made interference filter (from Pearson et al. 1976).

SPECTRAL DIFFERENCES BETWEEN LIVE AND DEAD VEGETATION

Live and dead plant leaf material are quite different in terms of how they interact with electromagnetic radiation or light. Green leaves, for example, absorb up to 90-95% of the blue and red radiation presented to them while recently senesced or dead leaves are much lower absorbers in the red region because of the reduced chlorophyll concentration present. Live and recently dead vegetation are more similar in the near infrared than red region as has been reported by Colwell (1974) and Tucker (1977b) but this depends upon the length of time the vegetation in question has been dead. Colwell (1974) has also reported that the red reflectance varies the most with vegetation maturity (i.e., conversion to standing dead material) and this has been corroborated by Tucker (1977b).

The theoretical basis then for spectroradiometric determination of live/dead percentages is the difference between live and dead vegetation in the red region of the spectrum and, to a lesser extent, the difference between live and dead vegetation in photographic infrared region of the spectrum.

METHODS AND MATERIALS

The experimental results reported herein were obtained in the animal production department's laboratory/tea room at the Grassland Research Institute, Hurley, Berkshire, UK in early May, 1977. The experiments were conducted on a laboratory bench as shown in Figure 1. Each radiometer probe was held

10 cm over the work area which was covered with black paper. Illumination was provided by the two desk-type lamps each equipped with 150W bulbs (Figure 1).

Fresh green perrenial rye grass (PRG) was combined with dead grass hay for experimental purposes. The rye grass was used both on a fresh weight basis and on a dry weight basis. Drying was accomplished by placing the freshly-cut grass material in a microwave drying-oven for 15 minutes. Four replications using both wet or dry green material were performed.

The actual mixing procedure involved weighing different proportions of green and dead material ranging from 0% green (100% dead) to 100% green (0% dead) in 20 gm samples. The respective components were manipulated to result in 11 samples per determination with different percentages of green material in each 20 gm sample at 10% increments (i.e., 0%, 10%, 20% . . . 100% green). For example, 0% green was in reality 20 gm of dead material and 0 gm of green material; 50% green was 10 gm dead and 10 gm green material, and so forth.

Each premeasured sample was thoroughly chopped-up using grass clippers until most of the grass material was ~1 cm in length. The material was removed from its respective plastic bag and arranged in a small symmetric and flat pile under the two probes. Great care was taken to insure that the thickness of the grass pile did not affect the readings. This, in turn, enabled the phenomena of asymptotic spectral reflectance or radiance to be utilized (Tucker, 1977a; Gausman et al., 1976).

A reading from each probe was then made and recorded. Subsequently, the grass sample was removed from the bench, thoroughly remixed, and placed back under the probe. A total of three red and ir readings were made per sample. Great care was made to have both the green and dead material be of about the same cut size. This was to avoid the settling out of the finer material. The mixtures measured were arranged in a pile with a diameter of $\sim 12\,cm$, were 2-4 cm thick, and were relatively smooth on the upper surface. Prior to each sample reading, a calibration reading was made from a $BaSO_4$ reference panel.

Two series of spectral measurements were made on each of the four replications which resulted in 8 series of spectral data. The data was subsequently processed by regression analysis to quantify the relationship(s) present. The averages of each of the three readings per sample were used in the regression analysis. Complete data listings for two of the determinations are presented in Appendix A.

The red and infrared radiance variables were evaluated as radiance variables and also as reflectance variables. The reflectance variables resulted from dividing the sample radiance readings by the $BaSO_4$ reference reading.

In addition to the red and photographic infrared radiance and reflectance variables, the infrared/red ratio and the (infrared - red)/(infrared + red) variables were evaluated. The difference divided by the sum is known as the vegetation index (VI).

Regression analysis of the reflectance and radiance data was used to evaluate the utility of this approach. A simple linear regression model w.. used.

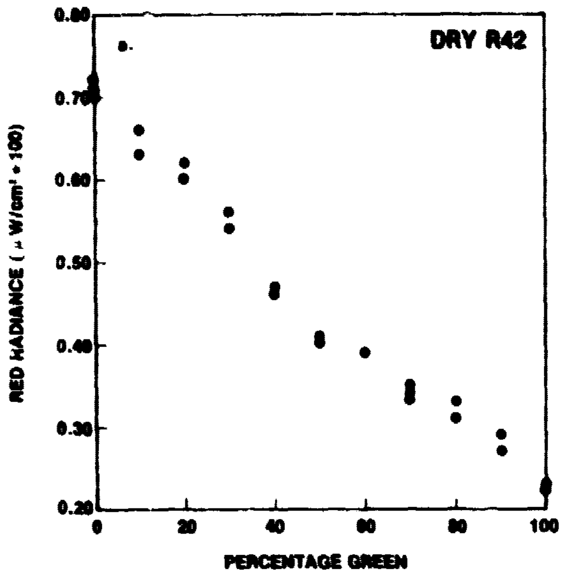
RESULTS AND DISCUSSION

The previously mentioned experimental procedure was carried out and evaluated by regression techniques for the four rep''cations (2 wet and 2 dry). In general, the results were basically the same although the replicates using dry green vegetation were more significant in a regression sense than the replicates using wet green vegetation (Table 1).

The use of the $BaSO_4$ reference readings did not improve regression significance for the various spectral variables evaluated. In fact, the radiance variables had slightly higher r^2 values than did the reflectance variables (Table 1).

The red radiance and VI were the spectral variables most highly related to the percentage of green material present (Figures 3, 4, and 5; Table 1). The samples which used dry green material were superior to those using wet green material.

The red reflectance and radiance variables both showed an inverse and close to linear tre d with increasing percentages of dead mate.ial. The photographic infrared reflectance and radiance variables showed a direct semi-linear trend with increasing percentages of green material. The photographic infrared measurements using the wet green material were more non-linear than the



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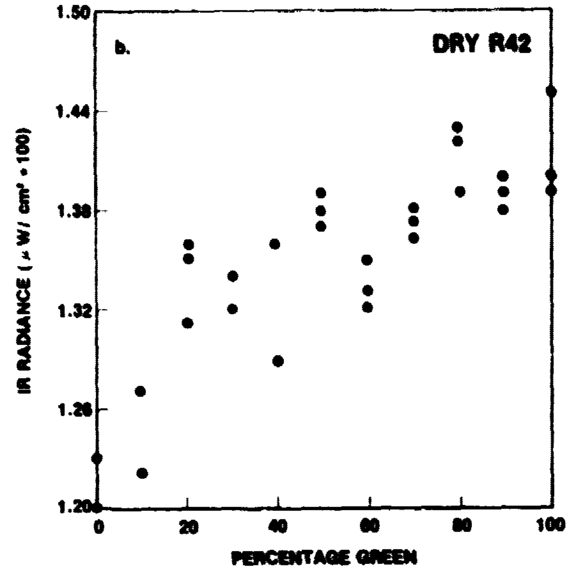

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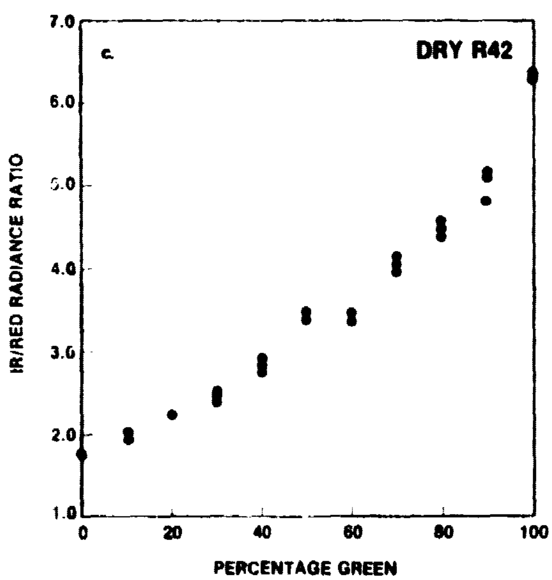

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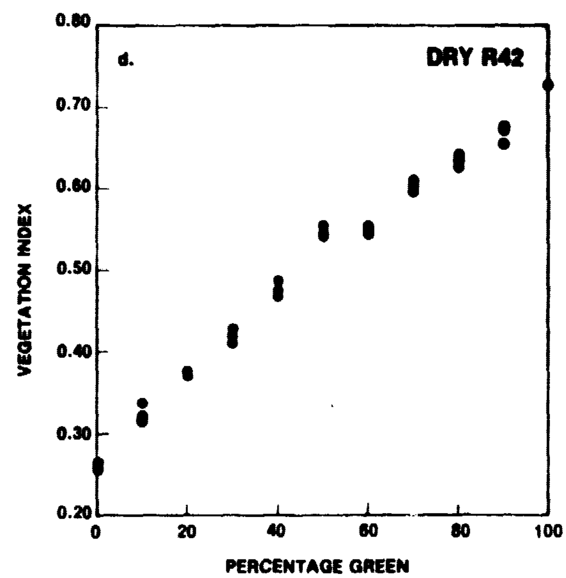
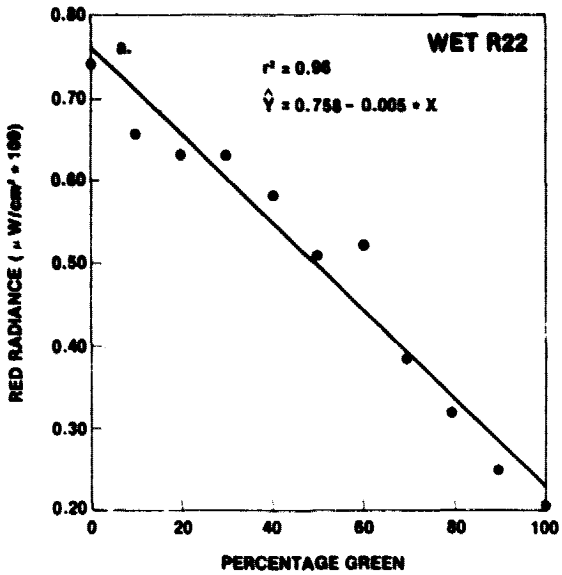


4d

Figure 3. The raw data from the dry green determination of replicate R42. The percentage of green material in each of the 20g samples is plotted against (A) the red radiance, (B) photographic infrared radiance, (C) the ir/red radiance ratio, and (D) the vegetation index (VI) of (ir - red)/(ir + red). The averages of these values are plotted in Figure 5.



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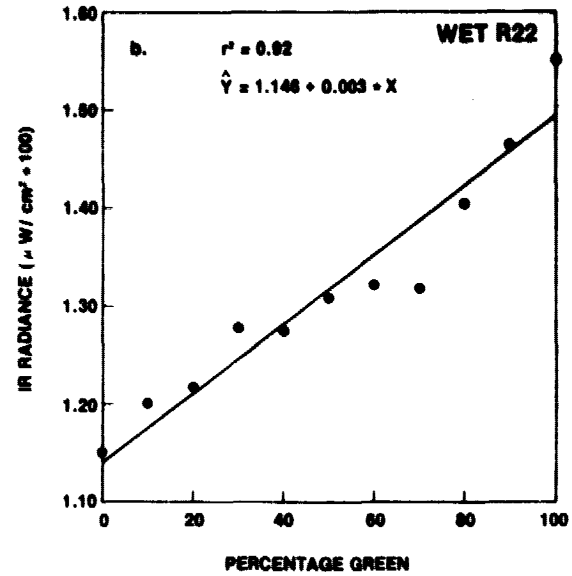

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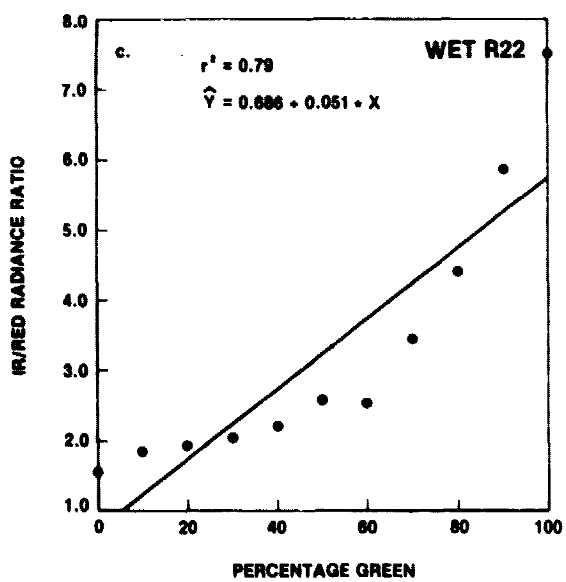

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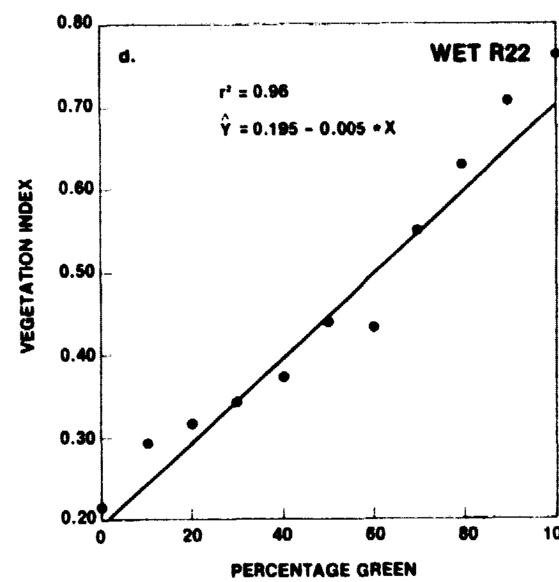
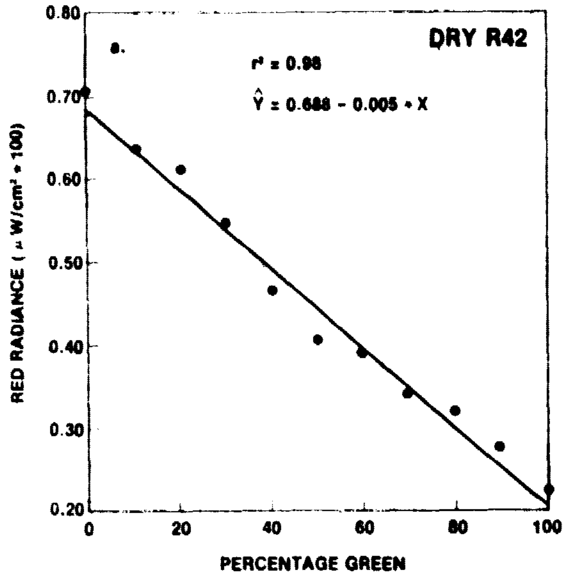


5d

Figure 4. The averaged data from the wet green determination of replicate R22. The percentage of green material in each of the 20 g samples is plotted against (A) the red radiance, (B) the ir radiance, (C) the ir/red radiance ratio, and (D) the VI of (ir - red)/(ir + red). Refer to Table 1 for tabular results.



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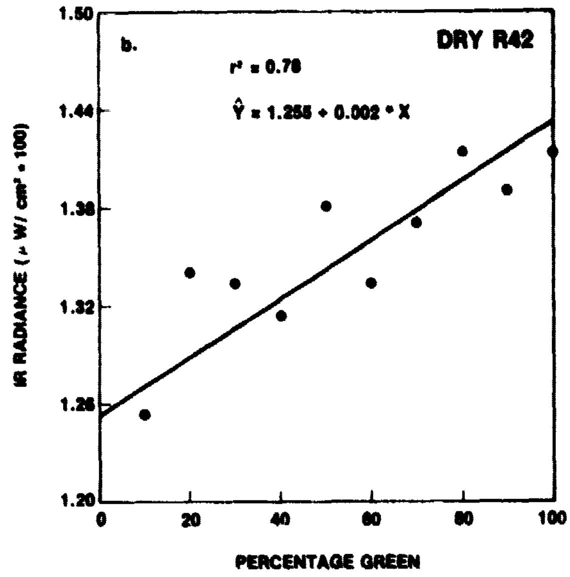

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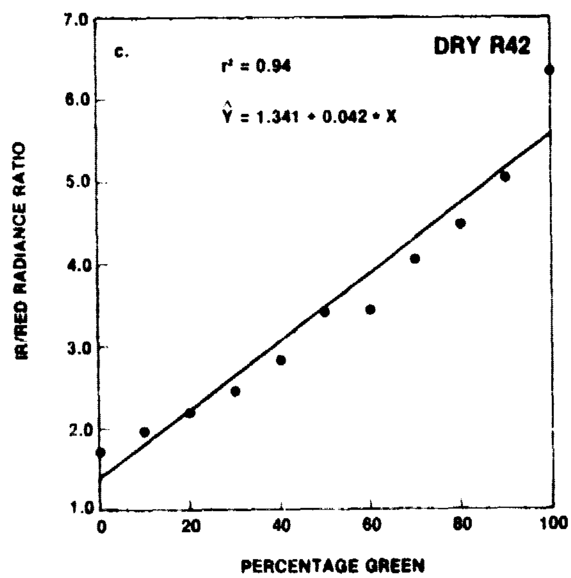

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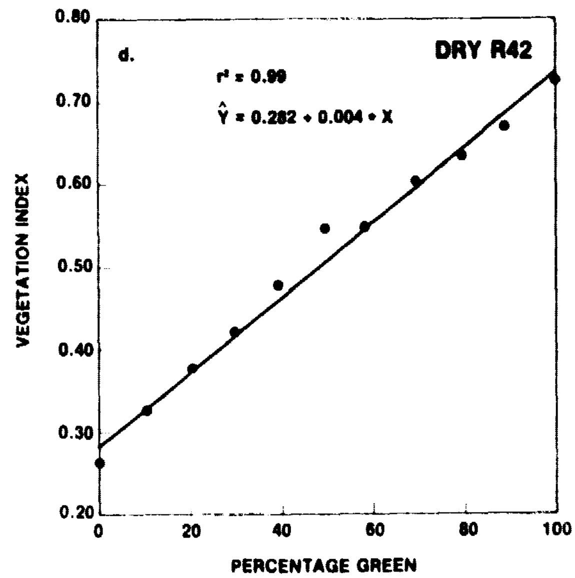

6d

Figure 5. The averaged data from the dry green determination of replicate R42. The percentage of green material in each of the 20g samples is plotted against (A) the red radiance, (B) the ir radiance, (C) the ir/red radiance ratio, and (D) the VI of (ir - red)/(ir + red). Refer to Figure 3 for the raw data and Table 1 for tabular results.

Table 1

Coefficients of determination (r^2 values) between the four spectral variables and the percentage of green material in the various samples. RAD = radiance, RFL = reflectance, Red = 0.650-0.700 μm, IR = 0.775-0.825 μm, IR/RED = radiance or reflectance ratio, VI = (ir - red)/(ir + red).

Variable	RAD	RFL	RAD	RFL	RAD	RFL	RAD	RFL
	Wet R 11		Wet R 12		Wet R 21		Wet R 21	
Red	.83	.92	.89	.89	.95	.92	.96	.94
IR	.67	.08	.76	.89	.81	.92	.92	.93
IR/RED	.91	.88	.80	.79	.78	.79	.79	.79
VI	.96	.93	.90	.91	.93	.95	.96	.95
	Dry R 31		Dry R 32		Dry R 41		Dry R 42	
Red	.97	.96	.99	.97	.98	.99	.98	.99
IR	.02	.02	.04	.43	.72	.54	.78	.65
IR/RED	.96	.96	.96	.97	.97	.96	.94	.94
VI	.98	.97	.99	.99	.99	.99	.99	.99

*Wet R 11, for example, refers to replicate 1 measurement number 1 using the Wet PRG. Wet R 12 refers to replicate 1 measurement number 2 for the Wet PRG, and so forth.

same measurements using dry green material. There was more scatter to the data for the photographic infrared measurements than for the red measurements (Figures 3, 4, and 5).

The ir/red ratio and the VI would be expected to exhibit the characteristics of their respective components. The ir/red ratio increases as the amount or percentage of green material increases. The determinations using the wet green material were very curvilinear while the ir/red ratios for the dry green material were more linear (Figures 3, 4, and 5).

The VI transformation showed a highly significant and linear relationship when plotted against the percentage of green material. The determinations using dry green material were, once again, more linear and hence had higher r^2 values for the linear regression models evaluated than the wet green material measurements. The VI for the dry green material had a r^2 value of 0.99 (Table 1; Figures 3d and 5d).

The red and VI radiance and reflectance variables were, without exception, most highly correlated with the percentage of green material for every wet or dry determination evaluated (Table 1). The various r^2 values for these variables were basically the same between the different replications. Therefore the use of one over the other is not indicated by the data analysis.

It is apparent, however, that a one probe device would suffice if only the red radiance or reflectance measurement was used. If this proves to be of sufficient utility, as the data analysis suggests, then a modest savings in equipment cost could be realized by only using a one probe (red) device.

A two-probe device does have some advantages, among them the use for *in situ* nondestructive green biomass determinations (Tucker and Smith, 1978). In addition, a two-probe instrument can compensate or adjust for slight variations in the intensity of the incident light source by using the VI transformation. Further research is needed to resolve the question if one probe with highly regulated light source intensity will suffice.

LIMITATIONS IN THE EXPERIMENTAL PROCEDURE

The experimental results reported herein are from an ideal and carefully selected experimental situation. The green vegetation was of only one species (PRG) and the dead vegetation was from 6 month old hay. The author is the first to admit that this is not a typical field situation but these were the only materials available at the time of this experiment.

The relationships between the red and VI variables and the percentage of green material present in the cut sample were very significant. The applicability to more usual field situations needs to be evaluated, both for cultivated pastures and heterogeneous grasslands. The degree to which the r^2 values reported herein will be reduced in actual field experimental applications must be determined. When this has been done for a variety of field situations, the applicability of this method can be compared in terms of precision and time expended vis-a-vis the traditional live/dead sorting methods. It should be stressed that the work reported upon here is a preliminary attempt at a spectral live/dead determination method.

A double sampling type of approach is envisioned where samples from the area in question are brought in to the laboratory. The first procedure would be to obtain representative samples of dead vegetation and green vegetation from the area in question. Both materials should be dried in a microwave oven for 10-15 minutes. Samples should then be composed varying from 100% green to 100% dead material at increments chosen by the experimenters. Ten percent increments are suggested as used in the experiment reported herein but additional research may suggest other increments.

Each sample should then be thoroughly cut or chopped and mixed. Care must be taken to avoid settling out of the finer-cut material. Multiple readings should be taken of each sample with remixings of the sample between readings.

When the calibration readings are completed, the relationship(s) between the radiance or reflectance variables used and the live/dead fraction should be computed using regression analysis. The actual field samples are then measured, using the same approach as the calibration procedure for cutting, chopping, etc. and converted to live/dead fractions by using the regression relationship(s). Actual samples can then be hand-sorted to compare the accuracy of the spectral method to that of the traditional technique. In addition, the accuracy of the traditional sorting technique can be determined by hand-sorting the premeasured calibration samples.

The spectral method should not be unilaterally compared with or judged by the traditional hand-sorting technique. Both methods involve an amount of determination error. Cross comparisons are therefore necessary and warranted to unbiasedly evaluate both methods and compare them.

CONCLUSIONS

1. A live/dead separation procedure using red and photographic infrared spectral measurements has been developed and tested on PRG and dead grass hay with highly significant results.

2. The red and vegetation index reflectance and radiance variables were the most useful for determining the percentage of green material present in cut grass samples.

3. Microwave drying of the PRG prior to weighing and combining it with the dead grass hay improved the regression results and resulted in more linear relationships than the use of wet green PRG.

ACKNOWLEDGMENTS

The author wishes to thank the Grassland Research Institute for their assistance and encouragement. Numerous scientific and philosophical discussions with Michael Wade are also acknowledged.

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APPENDIX A

Table A1

Raw data values from the WET R 22 and DRY R 42 series of measurements.
Refer also to Figures 3, 4, and 5.
All radiance units in this table are in $\mu W/cm^2 * 10^2$.

Number	% Dead*	Reference Measurement		Sample Reading Number					
				1		2		3	
		RED	IR	RED	IR	RED	IR	RED	IR
WET R 22									
1	0	2.3	2.3	.21	1.53	.21	1.53	.21	1.59
2	10	2.3	2.3	.24	1.46	.26	1.47	.25	1.46
3	20	2.3	2.3	.31	1.41	.33	1.39	.32	1.41
4	30	2.3	2.3	.37	1.29	.40	1.33	.38	1.33
5	40	2.2	2.3	.52	1.32	.53	1.31	.52	1.33
6	50	2.2	2.3	.50	1.29	.54	1.34	.49	1.29
7	60	2.3	2.3	.58	1.27	.60	1.29	.57	1.26
8	70	2.3	2.3	.64	1.29	.62	1.28	.63	1.26
9	80	2.4	2.3	.63	1.21	.63	1.24	.64	1.23
10	90	2.4	2.4	.64	1.18	.66	1.20	.67	1.22
11	100	2.4	2.3	.73	1.12	.75	1.15	.75	1.18
DRY R 42									
1	0	2.5	2.5	.23	1.45	.22	1.40	.22	1.39
2	10	2.4	2.4	.29	1.39	.27	1.38	.27	1.40
3	20	2.4	2.4	.31	1.42	.31	1.39	.33	1.43
4	30	2.4	2.4	.33	1.36	.35	1.38	.34	1.37
5	40	2.3	2.3	.39	1.35	.39	1.32	.39	1.33
6	50	2.4	2.4	.41	1.38	.40	1.39	.41	1.37
7	60	2.4	2.4	.47	1.36	.46	1.29	.47	1.29
8	70	2.4	2.4	.54	1.34	.56	1.34	.54	1.32
9	80	2.4	2.4	.60	1.31	.62	1.36	.62	1.35
10	90	2.4	2.4	.63	1.27	.66	1.27	.63	1.22
11	100	2.3	2.3	.71	1.20	.72	1.23	.70	1.20

*% Green = 100% - % Dead.