Technical Report No. 167

REMOTE SPECTRAL MEASUREMENTS AS A METHOD FOR DETERMINING PLANT COVER

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ABSTRACT

This technical report contains the progress report (January 1971 through January 1972) and the planning report (January 1972 through January 1973) for the Field Light Quality Laboratory of the Grassland Biome of the International Biological Program. Included in the report are descriptions of the investigation completed during 1971.

The most important result obtained from the year's investigation was the demonstration of a linear relationship between the standing green biomass on a grassland plot and the spectroreflectance from that same plot. This relationship will be utilized to develop a hand-held radiometer which will display directly the green biomass of the vegetation on the plot being viewed without the need of destructive clipping of the plot.

Another set of results is the determination of the spectroirradiance for a complete diurnal cycle beneath the gas analyzer dome of the IBP Grassland Biome field photosynthesis experiment. These data will be used to calibrate radiometrically the photocell used to measure the amount of incoming solar radiation by the photosynthesis experiment.

INTRODUCTION

This report covers a portion of the field spectrometry experiment funded by the National Science Foundation as part of the U.S. International Biological Program (IBP) Grassland Biome. It details the activities and experiments carried out during 1971, the data taken and preliminary results obtained, and the planned work for 1972. The report also briefly describes the additional equipment obtained and procedural changes made at the laboratory since the publication of the 1970 progress report (Pearson, Miller, and Ranson, 1971).

The data taken during 1971 were primarily spectroreflectance curves of natural, circular ¼ sq m plots of shortgrass prairie surface materials, such as live blue grama and buffalo grass, standing dead vegetation, and bare soil.

Ancillary data were also collected for each of these plots including the total wet and dry standing biomass of the plot's Ektachrome photographs and Ektachrome Infrared photographs. Also, the leaf area index as determined by the point quadrat method was measured for approximately one-half of the plots used, and additional descriptive data and measurements were obtained from selected plots including vegetation samples for chlorophyll analysis.

OBJECTIVES

The overall research objective of the field spectrometer experimentation is the development of a rapid, nondestructive method for sampling the cover and for determining biomass of the standing vegetation of the shortgrass prairie. The resulting method(s) of measurement will be applicable to either ground-based, simple analog meter measurements of sample plots or to aerial-based, synoptic determinations over large areas using remote multispectral sensing methods. The feasibility of the technique is being evaluated in this phase of the project, and a simple prototype field instrument will be built to test the method in actual field conditions. Appropriate aircraft remote sensing devices are already available to implement the synoptic aerial approach (Wagner and Colwell, 1968). However, accurate verification of both ground and aerial applications and results must await the implementation and testing of the simple prototype field instrument and further verification with the field spectrometer laboratory.

A complete description of the proposed sampling techniques and the measurements required can be obtained from previous technical and progress reports, and a detailed explanation will not be included here (see Pearson et al., 1971, p. 1-2; Pearson and Miller, 1971, p. 5-13; Miller, 1969, p. 4-6).

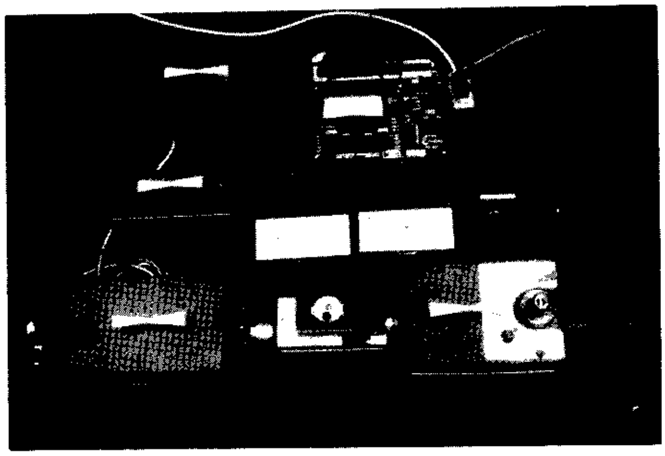
The field data taken and evaluated during 1971 have verified the original hypotheses regarding usable relationships existing between the spectroreflectance and spectroradiance from a shortgrass prairie and the amount of cover and biomass of the prairie plants. These preliminary results provide a basis for devising and testing a spectroradiometric method of determining standing total or green biomass of the grass cover on short and midgrass prairies. The primary objective of the next field season (1972) is to construct a prototype hand-held instrument which can be field tested on plots during the spring and summer growing season and to support it with further detailed spectrometer measurements of the same plots.

INSTRUMENTATION

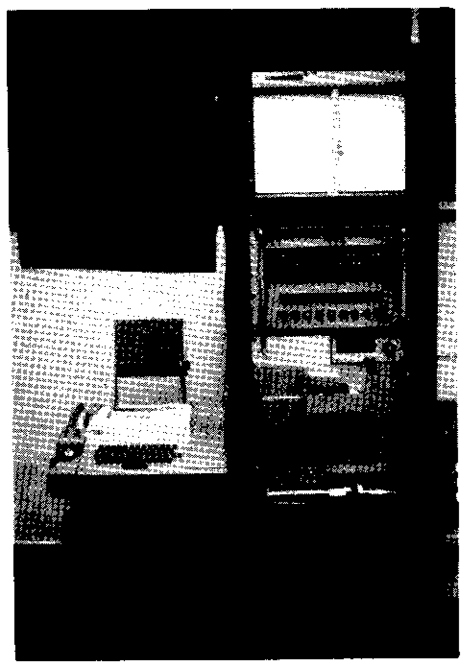
The basic field spectrometer laboratory, constructed to establish the spectroradiometric biomass-cover relationship, consists of (i) a spectroradiometric system (Fig. 1a), (ii) a computerized digital data acquisition and control system with x-y plotter for on-line spectroreflectance display (Fig. 1b), (iii) a field trailer to house the data acquisition systems, and (iv) an auxiliary portable power generator to supply operating power at remote sampling sites together with other ancillary logistical support equipment. A more detailed description of the laboratory equipment included in the field spectrometer laboratory can be obtained from previous IBP technical reports (Pearson et al., 1971, p. 3-7; Pearson and Miller, 1971, p. 14-36). Some modifications have been made to the laboratory since these earlier reports were written. They include modification of the interior of the field trailer, installation of a larger air conditioner, addition of a power conditioning transformer, construction of a larger folding mirror, and construction of an artificial field light source.

The interior of the field trailer was modified by installing more convenient storage cabinets above the working counter in the rear and by replacing the small 6,000 BTU/hr air conditioning unit with a larger 11,000 BTU/hr unit. This extra cooling capacity was necessitated by the unforeseen high heat penetration through the ceiling of the trailer, which was parked on the unshaded prairie.

The powerline conditioning transformer was added to isolate the data gathering equipment (particularly the spectroradiometer) from a 6 hertz powerline noise intermittently experienced at the Pawnee Site. The selected transformer compensates for this noise by rapidly adjusting its output voltage (up to 40 times/sec) to a constant value of 117 v. Because only the data



a.



b.

Fig. 1. a. The spectroradiometer system showing all of its components.
b. The computerized digital data acquisition system mounted in the rack used for indoor laboratory operation during the winter months. All of this equipment is mounted in a trailer for summer field use.

gathering systems (particularly the spectroradiometer) require the filtered power and because a transformer large enough to filter all of the power used by the laboratory would be much too heavy to be placed in the trailer, a transformer with a 1-kw power capacity was chosen. It was placed on the floor of the trailer closet and ventilated with a fan and an outside air vent.

Outside the trailer a larger, tripod-supported mirror was constructed (Fig. 2) to fold the field-of-view of the spectroradiometer down to the ground to subtend a ¼ sq m circular plot. The mirror is made of 26 × 40 inch plate glass, resulting in second surface reflection rather than first, and is mounted in a sheet metal frame and suspended from a 10-ft tripod. It is difficult to move and align this mirror over a marked plot because of its size, but it is the only practical means of viewing a larger, more typical ground plot with the spectrometer laboratory.

The final equipment addition made during 1971 was the construction of an artificial light source. The source consists of a plywood ring with 10 150-w flood lamps suspended underneath and directed toward the ground below (Fig. 3). The ring is mounted on three legs 1 m above the ground and has a hole large enough to allow a ground plot of ¼ sq m to be viewed vertically through it using the large tripod-mounted mirror mentioned above (Fig 2). A wire mesh form fitted with a black felt cover is used to shade the light ring and enclosed plot from the varying natural sunlight (Fig. 3).

Several computer software and laboratory procedural changes were made to allow the collection of new types of data during the 1971 field season. Before the season the laboratory was set up to measure ratios of spectral light qualities of plots, such as a spectroreflectance or spectrotransmittance (Pearson and Miller, 1971, p. 37-38). The capabilities of the laboratory

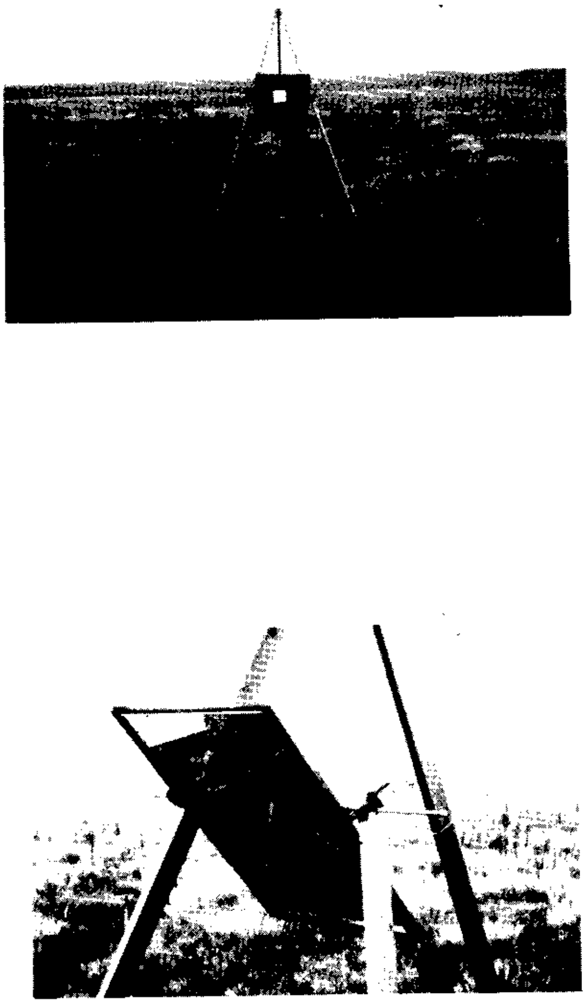
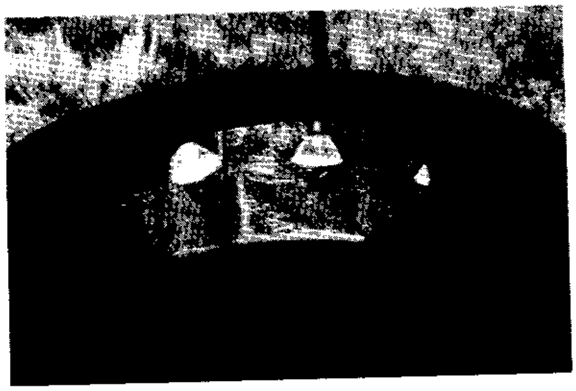


Fig. 2. Large-view folding mirror used to enable the observation of ¼ sq m plots by the spectroradiometer.



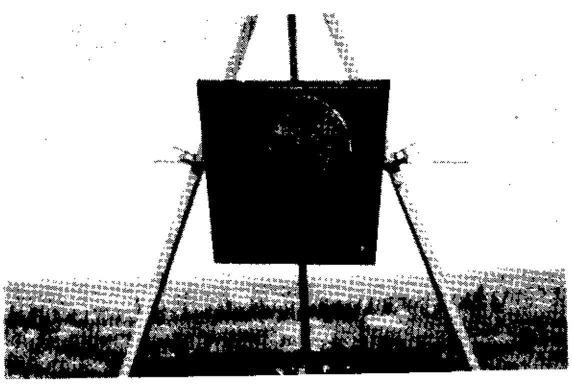


Fig. 3. Shaded light ring which contains ten 150-w cool beam bulbs to artificially illuminate ¼ sq m plots.

have been extended to gather calibrated spectroradiance or spectroirradiance data and irradiance or radiance at a single selected wavelength, such as the photosynthetically important .68 μm band. Also, supporting data (such as wind speed, temperature, etc.) are gathered automatically as a function of time. New software routines were prepared to enable the computer data collection system to accomplish these tasks, and new techniques were established for the laboratory operating personnel. The equipment flexibility designed into the field laboratory during its initial construction made this possible with no hardware modifications to the data gathering and recording instruments.

The collection of calibrated spectroirradiance or spectroradiance data was accomplished by using a new FORTRAN data collection routine (RAID) on the Hewlett-Packard mini-computer model no. 2114A. This routine applies the spectroradiometer calibration curves supplied by the spectrometer manufacturer to the raw spectroradiometer input data. It then outputs the data in the form of plotted spectroradiance curves and punched paper tape in the units of watts per square centimeter per micrometer per steradian. These data can easily be integrated and converted to other radiometric or photometric units to check the calibration of other solar measurement devices such as the pyranometers or solar cells used by other experimenters.

The automatic collection of various input data, as a function of time by the computer, is accomplished by using the Data Acquisition and Control Executive (DACE) software supplied by the computer manufacturer. The DACE software system directs the computer to execute certain routines such as data input, data processing, or data output tasks at selected time intervals ranging from one to several thousand seconds. The execution time intervals as well as any desired processing constants can readily be changed by the operator without stopping the data collection sequence.

One DACE routine (TASK 1) was written to record spectroirradiance data in synchronization with photosynthesis data as a function of time. The computer, when under the control of this program, is connected to both the data recorder in the photosynthesis trailer and the spectroradiometer which is collecting irradiance data via the fiber optics probe beneath the gas analyzer system plexiglass dome. The resulting data from both systems are automatically sampled at selected time intervals by the computer, converted to proper units, and output on punched paper tape for future analysis.

DATA GATHERED DURING 1971

The field data taken during 1971 at the Pawnee Site by the spectrometer laboratory was organized during its collection by sample numbers into several series relating to different experiments. Table 1 is an inventory of the most important of the 800 field spectral curve segments taken during 1971. The table does not include test data taken during the early part of 1971, prior to moving to the field site to test the equipment and data collection methods. Also not included are the data taken in support of James Tucker's experiments which are described in a separate 1972 IBP technical report (in preparation). Meaningful field data collection did not commence until July 20. This is a result of the unforeseen equipment problems in the field (such as the powerline noise, which had to be remedied before serious data collection could begin). Since the data collection began so late in the growing season, most of the experiments were conducted in the irrigated pasture at the Pawnee Site where the vegetation remained green and lush throughout the summer months.

The spectral curves measured are stored in three different forms. The first is the original graph of the ratios of light quantity made as the data

Table 1. Summary of the 1971 spectro-optical measurements by the field spectrometer project. This does not include test data prior to July 20 or data taken in support of other IBP spectrometer experiments.

Date		Plots Sampled	Number Sampled	Illumination	Comments
Gregorian	Julian				
July 20	201	2001-2033	33	Natural[a/]	Spectroreflectance of Kentucky blue grass and soil
July 30	211	4001-4042	42	Natural	Spectroreflectance of wheat stubble and cottonwood trees
Aug. 2	214	5001-5011	11	Natural	Spectroreflectance of sugarbeet and blue grama
Aug. 3	215	6000-6020	21	Natural	Spectroreflectance of $\frac{1}{4}$ sq m clipped plots
Aug. 10	222	6021-6030	10	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 11	223	6031-6034	4	Artificial[b/]	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 11	223	7000-7023	14	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 12	224	7011-7020	10	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 13	225	7011-7020	7	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 16	228	8000-8007	8	Natural	Bidirectional spectroreflectance of sage
Aug. 17	229	9000-9009	10	Artificial	Spectroreflectance of $\frac{1}{4}$ sq m clipped plots

Table 1 (continued).

Date		Plots Sampled	Number Sampled	Illumination	Comments
Gregorian	Julian				
Aug. 23	235	7024-7025	2	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 26	238	11000-11060	61	Natural	Spectroirradiance beneath gas analyzer dome
Aug. 27	239	12001-12021	21	Artificial	Spectroreflectance of combinations of Munsel chips
Aug. 29	241	9010-9011	2	Natural	Spectroreflectance of bare soil
Aug. 29	241	9012-9017	6	Artificial	Spectroreflectance of bare soil and $\frac{1}{4}$ sq m clipped plots
Aug. 30	242	10001-10007	7	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 31	243	10010-10020	10	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 31	243	10033-10036	4	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Aug. 31	243	10101-10115	14	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Sept. 1	244	10021-10032	12	Natural	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Sept. 1	244	10131-10132	2	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Sept. 1	244	10137-10150	8	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots
Sept. 2	245	10116-10136	15	Artificial	Spectroreflectance of undisturbed $\frac{1}{4}$ sq m plots

Table 1 (continued).

Date		Plots Sampled	Number Sampled	Illumination	Comments
Gregorian	Julian				
Sept. 3	246	14000-14035	37	Natural and artificial	Spectroreflectance of undisturbed ¼ sq m plots as a function of time of day and type of illumination
Total			371		

a/ Natural solar illumination measurements were made on relatively clear days with no clouds in the area of the sun.

b/ Artificial illumination was used on cloudy days and sometimes at night using the light ring with the felt skirt excluding most natural illumination.

curves were taken. The second is the punched paper tape of the data curves made on-line in the field by the laboratory's data acquisition system. The third is a magnetic computer tape being transcribed at the University of Colorado Computer Center from the punched paper tapes. This magnetic tape data will be placed in the U.S. IBP Grassland Biome central data bank for use by other investigators in the Grassland Biome. Typical spectroreflectance and spectroradiance data for one spectral curve are included in Appendix I.

EXPERIMENTATION PERFORMED DURING 1971

Munsel Chip Experiments

The most complex spectroreflectance method for determining the percentage of different constituent components within a given plot requires that the spectroreflectance of each of the components be known (Miller, 1969, p. 11-12). Naturally occurring objects can change slightly in spectroreflectance from plot to plot or even from place to place on a single plot. Therefore, for the initial evaluation of this spectral method, Munsel color chips which have constant, easily measured spectroreflectances were used in various patterns. These chips were arranged in varying numbers and patterns within the spectroradiometer's field of view.

The first determination used two Munsel chips, each covering half of the radiometer field of view (Fig. 4). The chips chosen were red and blue colors which have different spectroreflectances. The combined measured spectroreflectance curve of the equal combination of these two chips is 50% of the spectroreflectance of each of the individual chips (Fig. 5). These curves were analyzed spectrally to determine the percentage of each chip viewed in the combined view using the algorithm previously outlined (Miller

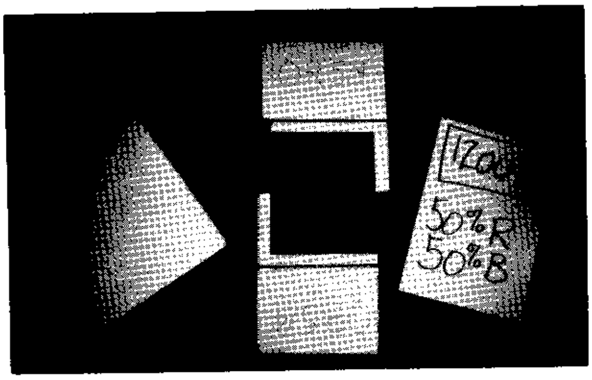


Fig. 4. Two Munsel chips as viewed by spectroradiometer. The actual area viewed (approximately 10 cm in diameter) is shown by the black circle. Note that equal areas of both the red Munsel chip and the blue Munsel chip were viewed as nearly as could be arranged. The red chip is the upper one and the blue one the lower.

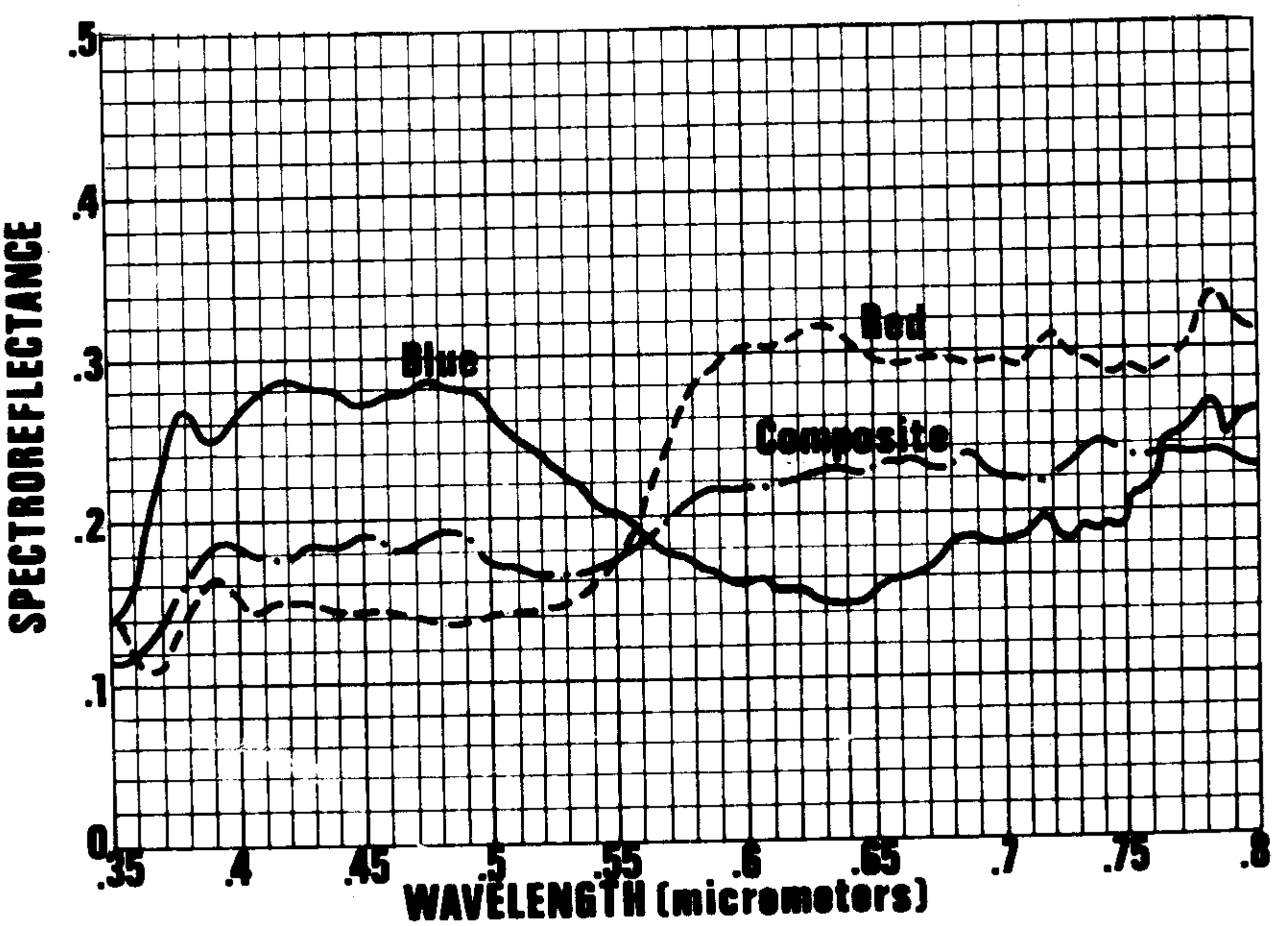


Fig. 5. Spectroreflectance data curves for the two Munsel Chips experiment. Note that the composite curve is approximately midway between the blue and red curves for all wavelengths.

and Pearson, 1971). A transformation of the equation describing a composite spectroreflectance in terms of its constituent spectroreflectances is made

$$C\lambda = \alpha R\lambda + \beta B\lambda \quad (1)$$

where

$C\lambda$ = composite reflectance at wavelength λ

$R\lambda$ = red chip reflectance at wavelength λ

$B\lambda$ = blue chip reflectance at wavelength λ

α = ratio of red chip area to area of projected field of view

$\beta = 1 - \alpha$

Substitution for β and rearrangement of equation (1) gives:

$$C\lambda - B\lambda = \alpha(R\lambda - B\lambda) \quad (2)$$

The transformed values $C\lambda - B\lambda$ and $R\lambda - B\lambda$ are calculated for each .05 μm wavelength band sampled between .35 and .8 μm to yield 91 sets of values for the visible spectral band. These 91 values were then input to a multiple linear regression routine with $R\lambda - B\lambda$ as the independent variable and $C\lambda - B\lambda$ as the dependent variable to yield a least-square regression estimate of α (the relative fraction of the red chip viewed).

The first attempt at estimating α from the spectral data was made with the least-squares line being forced through the origin as indicated by equation (2). However, when plotted the transformed data do not pass through the origin as expected due to a shift in the raw data obtained by the spectrometer system (Fig. 5). Therefore, a second pass was made through the multiple regression routine that computed both an intercept and a slope (α). The computer-plotted results (Fig. 6) show a reasonably good linear correlation among the data with a computed correlation coefficient of .99 and an estimate

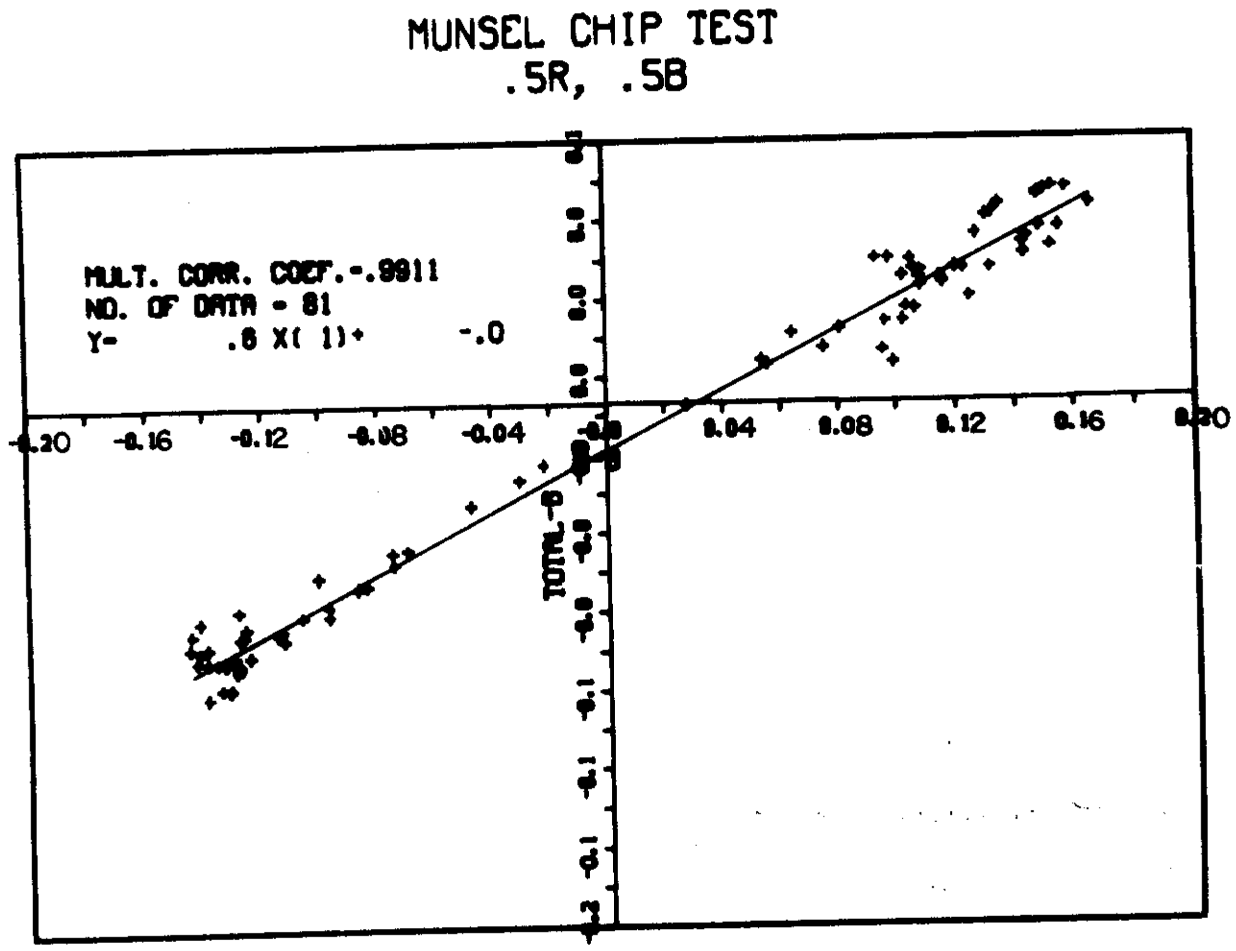


Fig. 6. Computer generated regression plot of transformed data from combined spectroreflectance curve for the two Munsel chips experiment. This analysis predicts 58% of red chip viewed and 42% of blue chip.

for α of .58 instead of the .50 established by the spectrometer operator at the time of the experiment. The standard error of the estimated α was calculated to be .009 (roughly 2%), indicating that the computed value of α has little relative variation about its mean. The value of α estimated by the regression routine was significantly different from the value established by the spectrometer operator. The calculated Y intercept is not significantly different from zero.

A second solution was made using three Munsel color chips arranged so that one-half of the field of view was covered by a green chip, one-quarter was covered by the red chip, and the remaining quarter was covered by the blue chip (Fig. 7). Again the resulting composite spectroreflectance curve reflects the spectroreflectance characteristics of each of the constituent curves according to the amount of each viewed (Fig. 8). The reflectance equation is again transformed into a linear regression form as in equation (2) above and the multiple linear regression performed (Fig. 9). When all of the data sets for the 91 wavelength samples of .05 μm in width between .35 μm and .8 μm were used, a multiple regression estimate of the percentage of the green, red, and blue areas measured was 50%, 0%, and 50%, respectively.

The experiments using the two and three Munsel chips were performed under the artificial light source, which is about five times weaker than noon solar illumination. The spectroradiometer sensitivity is lowest at its upper and lower wavelength limits for each detector grating combination. Therefore, the questionable upper and lower ends of the data curves (collected under the artificial light) were excluded, and the regressions were rerun. Using what is thought to be a more accurate subset of the data curve (constituting 41 wavelength samples from .55 μm to .75 μm) the estimates were 52%, 21%, and 27% for the three Munsel chips experiment. This is quite close to the

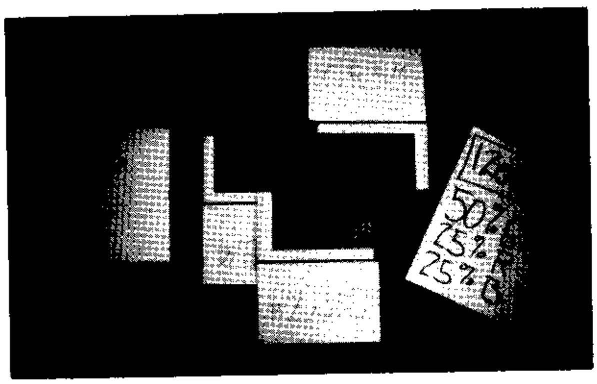


Fig. 7. Three colored Munsel chips integrated by spectroradiometer. The actual area viewed is shown by the black circle. Green chip at bottom is 50%, blue chip in upper left is 25%, and red chip in upper right is 25% of field of view.

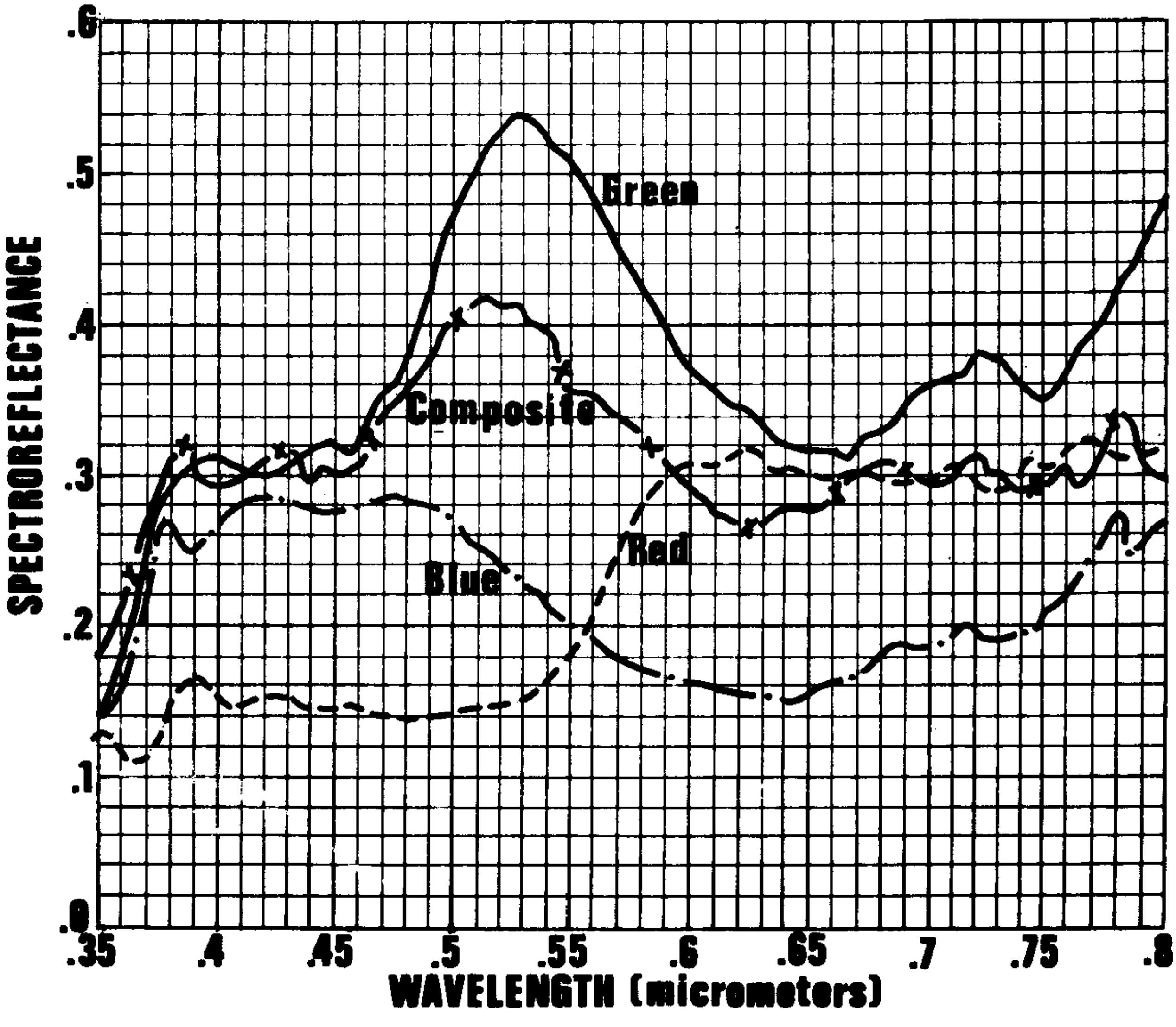


Fig. 8. Individual and composite spectroreflectance curves for the three Munsel chips experiment. Note that the composite curve is close to the green Munsel chip curve for all wavelengths.

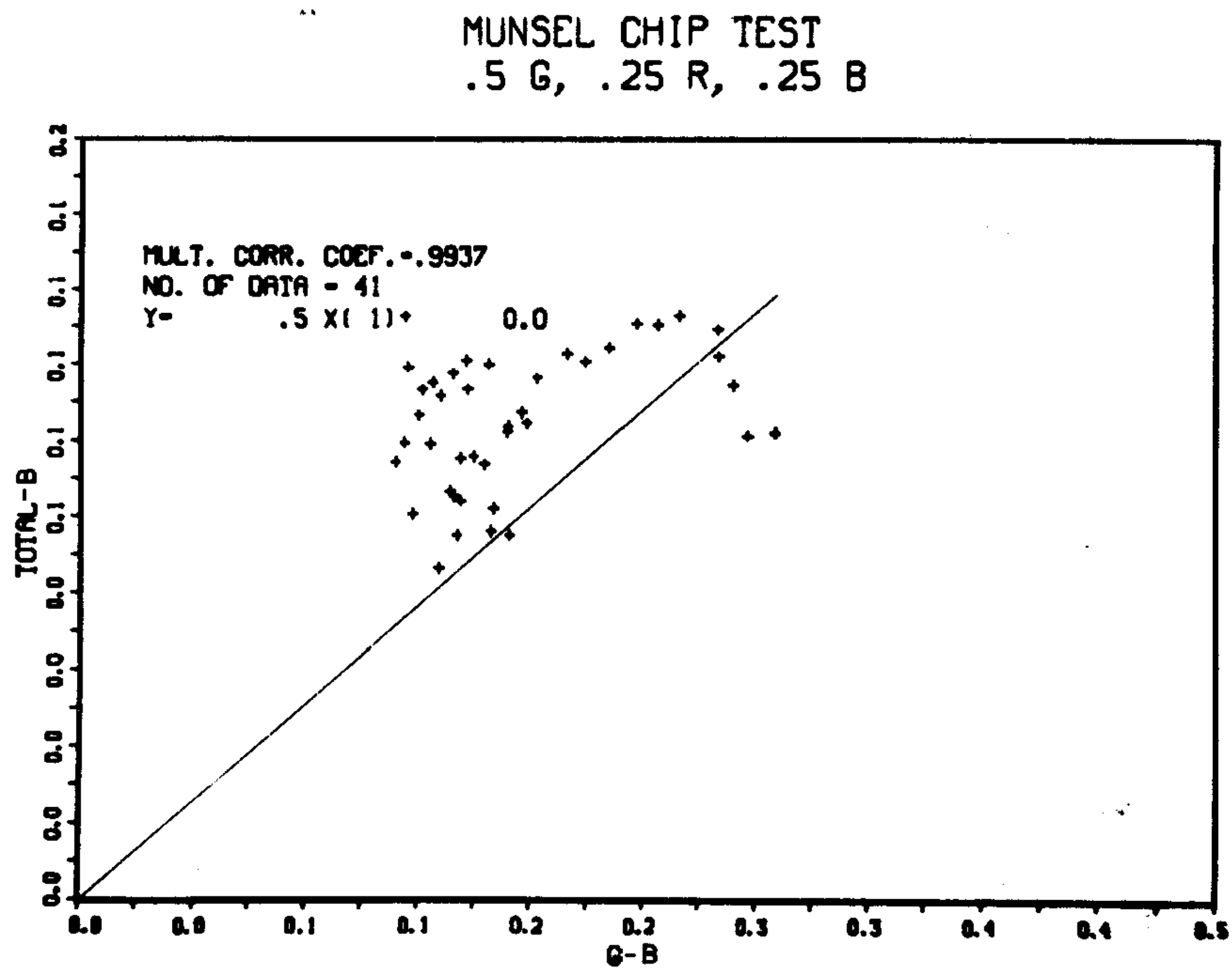


Fig. 9. Transformed regression data from combined spectroreflectance curve for the three Munsel Chips experiment. Each curve is adjusted for the variations in the other reflectance plot.

a. Adjusted composite minus blue is plotted as a function of green minus blue.

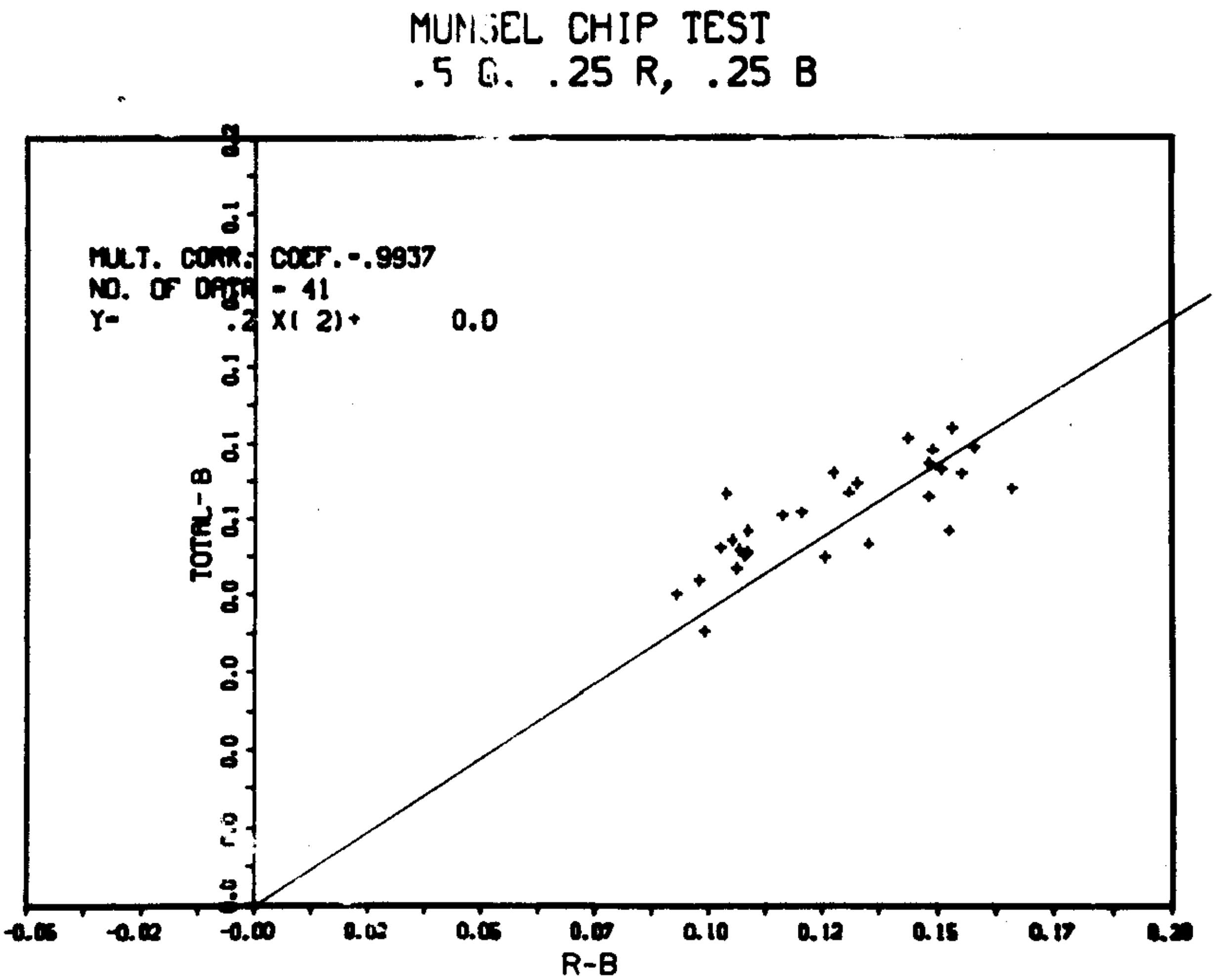


Fig. 9 (continued).

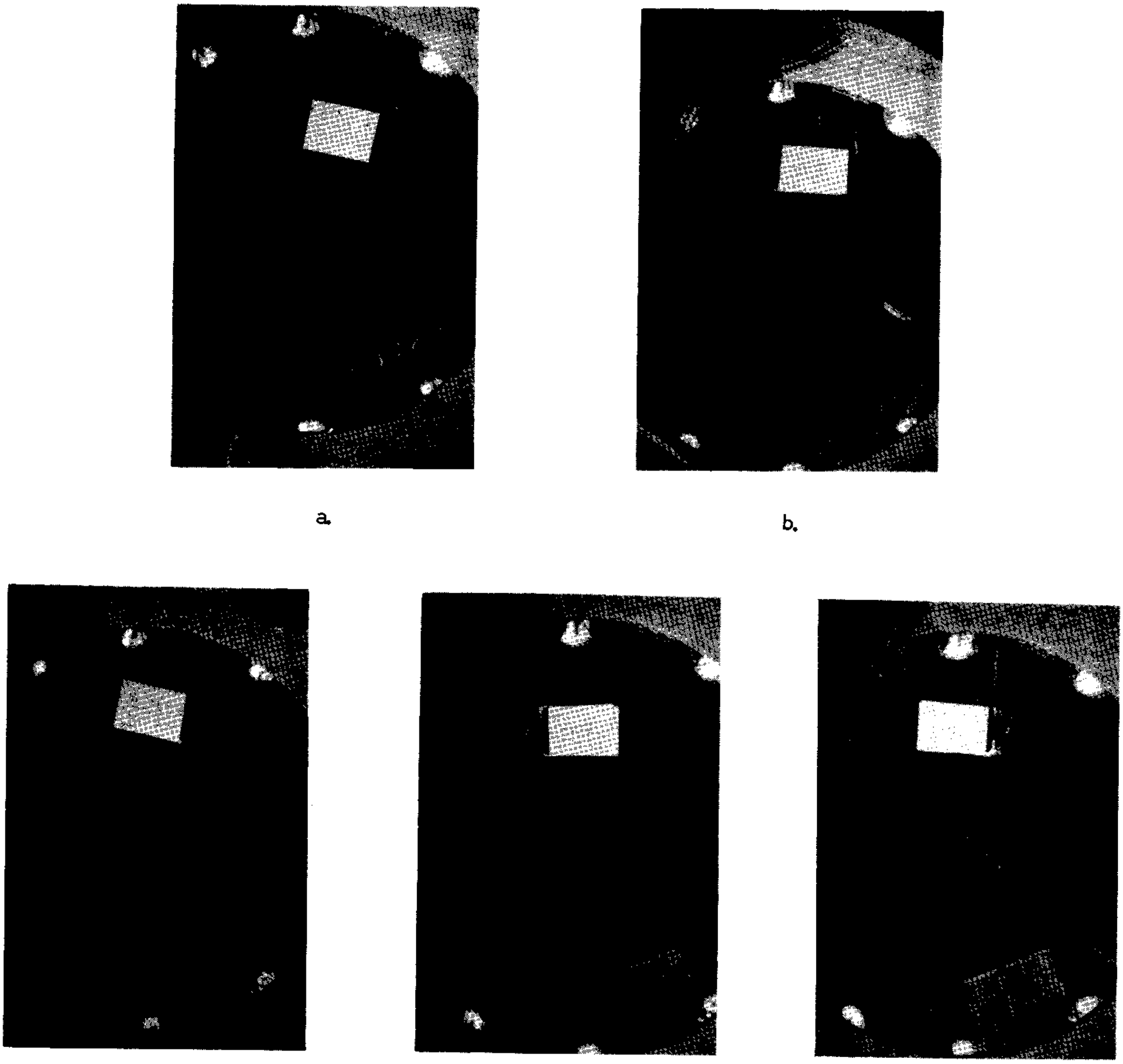
b. Adjusted composite minus blue is plotted as a function of red minus blue.

actual values established by the operator for field measurements. The two attempts with three materials for regression solutions forced through the origin according to equation (2) resulted in multiple correlation coefficients of .98 for the first run with the wider spectral band and .99 for the second run with the reduced spectral band. This indicates that the coefficients calculated by the multiple regression routine are very sensitive to small variations in the spectral data from both the individual and composite curves, caused by noise or instrument drift.

One-quarter Square Meter Area Clipped Plots

The next series of experiments was conducted to test the system's response to artificially created variations in percent cover of natural, green prairie grasses in a single ¼ sq m plot. The experiment was conducted using a natural grass plot of *Bouteloua gracilis* with a standing cover of 183.6 g/m^2.

First, the spectroreflectance was measured for the unmodified plot. Next, a wedge-shaped section equal to one-fourth of the plot's area was clipped out and the spectroreflectance was again determined for the total plot (Fig. 10). This process was continued until the entire plot had been clipped, and a curve was obtained for the bare, relatively undisturbed soil and litter. These curves plotted on one graph demonstrate the expected ordering of the curves as the green grass was clipped from the plot (Fig. 11). The difference, at any wavelength between the curve of the unmodified plot and the plot after it is entirely clipped, is divided into equal intervals by the curves of the plot when it is one-fourth, one-half, and three-fourths clipped. These in situ spectroreflectance curves obtained by the field spectrometer vary with the amount of green vegetation on the plot in an orderly and predictable manner.



a. b. c. d. e.

Fig. 10. A grass plot successively clipped in quarters to simulate known variations in cover. A quarter of the plot was clipped away for each successive spectroreflectance measurement. The biomass values shown are for the remaining standing grass crop in the area within the ring as these were determined by the standard Grassland Biome procedures.

a. Undisturbed--183.6 g/m^2.
b. One-fourth clipped--142.8 g/m^2.
c. One-half clipped--87.3 g/m^2.
d. Three-fourths clipped--42.6 g/m^2.
e. Entirely clipped--$\sim$0 g/m^2.

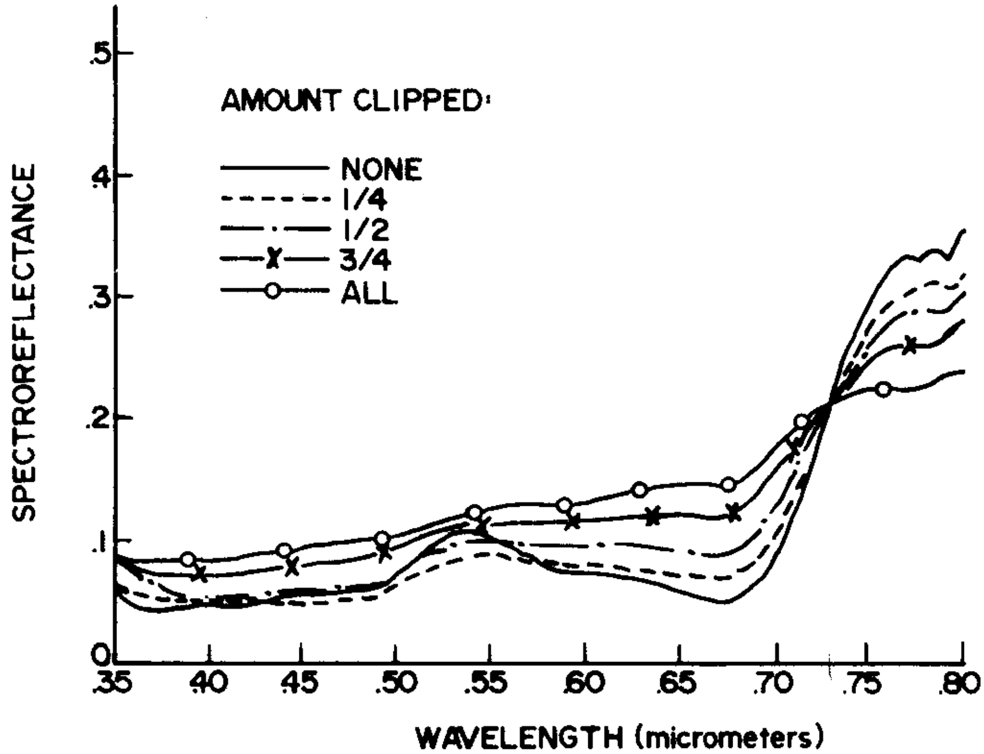


Fig. 11. Spectroreflectance curves from a plot whose cover was modified by known amounts. The intermediate curves are generally equally spaced between the limiting curves, especially from .55 to .8 μm.

One-quarter Square Meter Area Undisturbed Plots

The most extensive series of measurements made with the laboratory during 1971 was the spectroreflectance of undisturbed ¼ sq m plots of shortgrass prairie, predominantly blue grama. These experiments were conducted in the irrigated plots of the Pawnee National Grassland as outlined earlier. The plots studied are not typical of an undisturbed area of shortgrass prairie in late summer. The condition of the sample plots was deliberately selected to be representative of the green vegetation growth period in June. These measurements were made using a large number of ¼ sq m plots encompassing as wide a variation of grass cover and biomass as could be found. The plots were equidistant from the laboratory trailer in a sector of a circle so that each could be viewed in turn by a slight rotation of the spectroradiometer or trailer. Each plot was photographed vertically at the time it was being measured by the spectroradiometer with both Ektachrome and Ektachrome Infrared film (Fig. 12) so that an estimate could be made of the percentage composition of each of its surface constituents using the projected photograph techniques (Pearson and Miller, 1971, p. 101-102).

Three important surface constituents were present on the plots: green vegetation, dead vegetation, and soil. Spectroreflectance curves were determined separately several times for each constituent (Fig. 13). The in situ composite spectroreflectance for each plot was obtained twice, once using natural sunlight on relatively cloudless days and once using artificial light from the light ring described earlier. The curves from the same plot for both types of illumination in general were the same as is expected from the definition and method of determination of spectroreflectance (Pearson and Miller, 1971, p. 7-9) except for shadows cast at lower sun angles.

a.

b.

c.

d.

Fig. 12. Examples of the grassland plots used for the undisturbed plot experiment. Note the wide variation in vegetation cover of the plots. The vegetation is essentially *Bouteloua gracilis* with total standing biomass values shown for each plot as determined by standard clipping techniques.

a. Plot 7000--203.9 g/m^2.
b. Plot 7009--71.7 g/m^2.
c. Plot 7011--74.4 g/m^2.
d. Plot 7019--174.92 g/m^2.

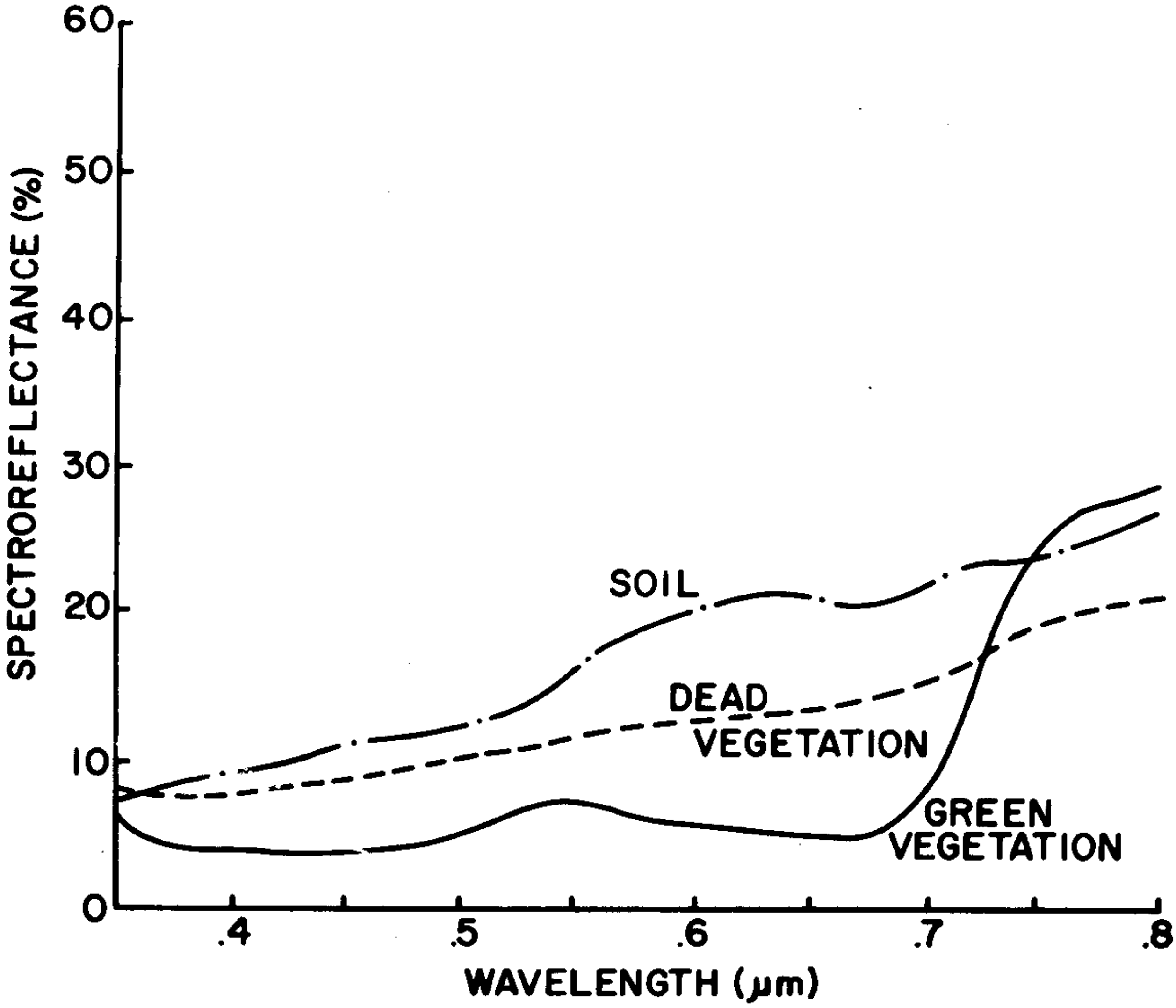


Fig. 13. Spectroreflectance of important constituents comprising the undisturbed ¼ sq m plots.

The scheme sought in this line of experimentation should spectrally separate green vegetation from dead vegetation and soil. The wavelength region from .65 to .8 μm is of interest because of the dissimilarity of the curves of these materials in this region. For the initial determinations to reduce the amount of data handled, two specific wavelengths of .68 to .78 μm were chosen for further detailed analysis.

The first inspection of the spectral data was made by plotting the reflectance at .68 μm from each of 27 undisturbed ¼ sq m grass plots against the total standing biomass clipped from each plot using all field measurements with no points or plots rejected (Fig. 14). A least-squares line was fitted through this data using REGRES, a multiple regression routine. The equation of the best fit line gives an inverse relationship between total grass biomass and reflectance at .68 μm with an R (correlation coefficient) of .70. The inverse relationship results because .68 μm is within one of the chlorophyll absorption bands.

Next, the total biomass of each of these same plots was plotted as a function of the reflectance at .78 μm (Fig. 15). Again, a least-squares line was fitted through the data points, but this time a direct relationship resulted with an R of .84. This direct relationship results because .78 μm is in the near infrared portion of the spectrum, a region of maximum reflectance for vigorous, turgid green vegetation. Both of these relationships exhibit fair linear trends by their correlation coefficients (R) of .7 and .84, respectively. The two selected wavelengths each relate to independent biophysical characteristics of the vegetation, which in turn relate to the amount of green biomass present on the plot. Therefore, it was anticipated that a mathematical combination of reflectances at both wavelengths might

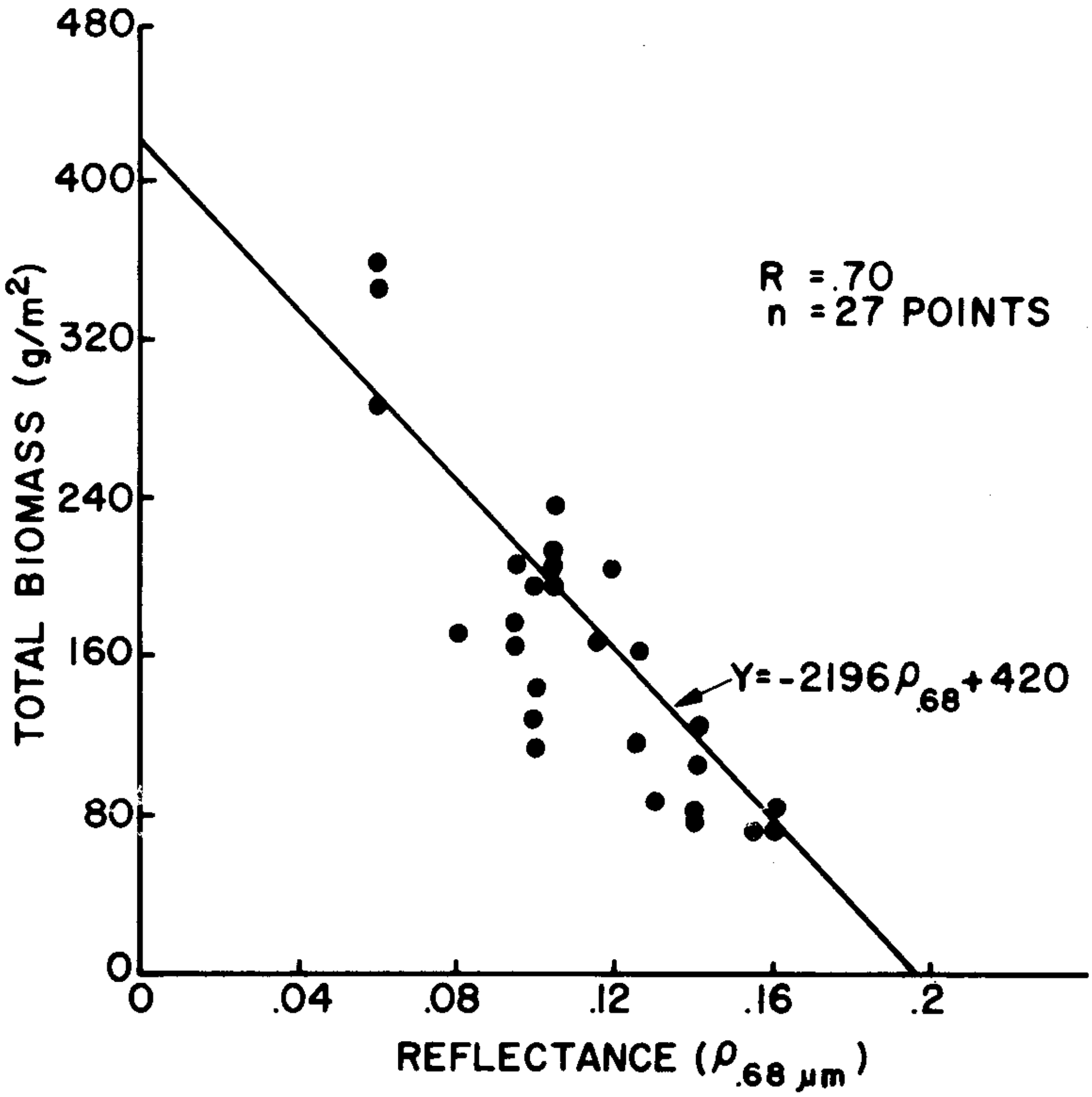


Fig. 14. Regression of the reflectance at .68 μm (ρ.68 μm) vs. total biomass for 27 undisturbed grassland plots (7000 to 7026). No field data points were rejected, and all 27 plots were used in the calculations.

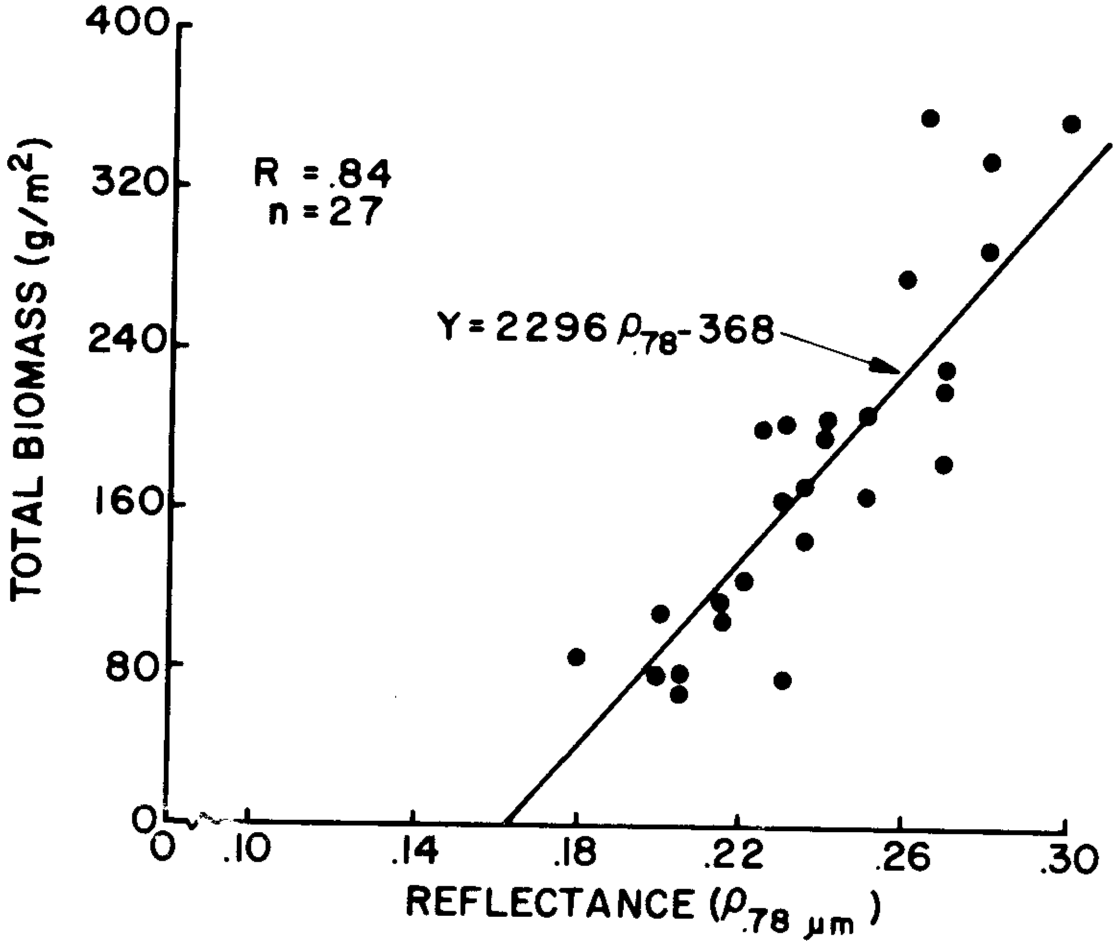


Fig. 15. Regression of the reflectance at .78 μm (ρ.78 μm) vs. total biomass for 27 undisturbed grassland plots (7000 to 7026).

yield an even higher correlation with total standing biomass than the reflectances taken separately.

The first combination attempted was the difference in the reflectance at .68 μm and that at .78 μm. Using this difference, the dry litter and soil of the plots with low cover yielded a much lower combined value (Fig. 13). This combined spectral characteristic is high with heavy green cover which is actively functioning and absorbing the .68 μm energy for photosynthesis and reflecting the .78 μm energy. The linear correlation between this single combined spectral characteristic and total standing biomass resulted in a correlation coefficient of .88 (Fig. 16). However, since these two wavelength bands were deliberately chosen to discriminate green vegetation from dead vegetation and soil, a plot of standing green biomass yielded an even better correlation of .91 (Fig. 17) as a function of the reflectance difference. Note that green biomass was separated from total clipped biomass by density and color using standard U.S. IBP Grassland Biome methods. Finally, vertically projected green cover (determined from the color photographs taken of each plot) was plotted as a function of this reflectance difference, and a still better correlation coefficient of .94 was obtained (Fig. 18).

The second combination of the two wavelengths used was the ratio of the reflectance at .78μm to that at .68 μm. When this was plotted against only the green biomass of 24 undisturbed plots (three plots were removed due to missing green biomass data), a correlation coefficient of .91 was obtained (Fig. 19). An inspection of the plotted data shows a small cluster of four points which lies off the linear trend of the remaining 20 data points. Rejection of these four points results in a correlation coefficient of .98 (Fig. 20).

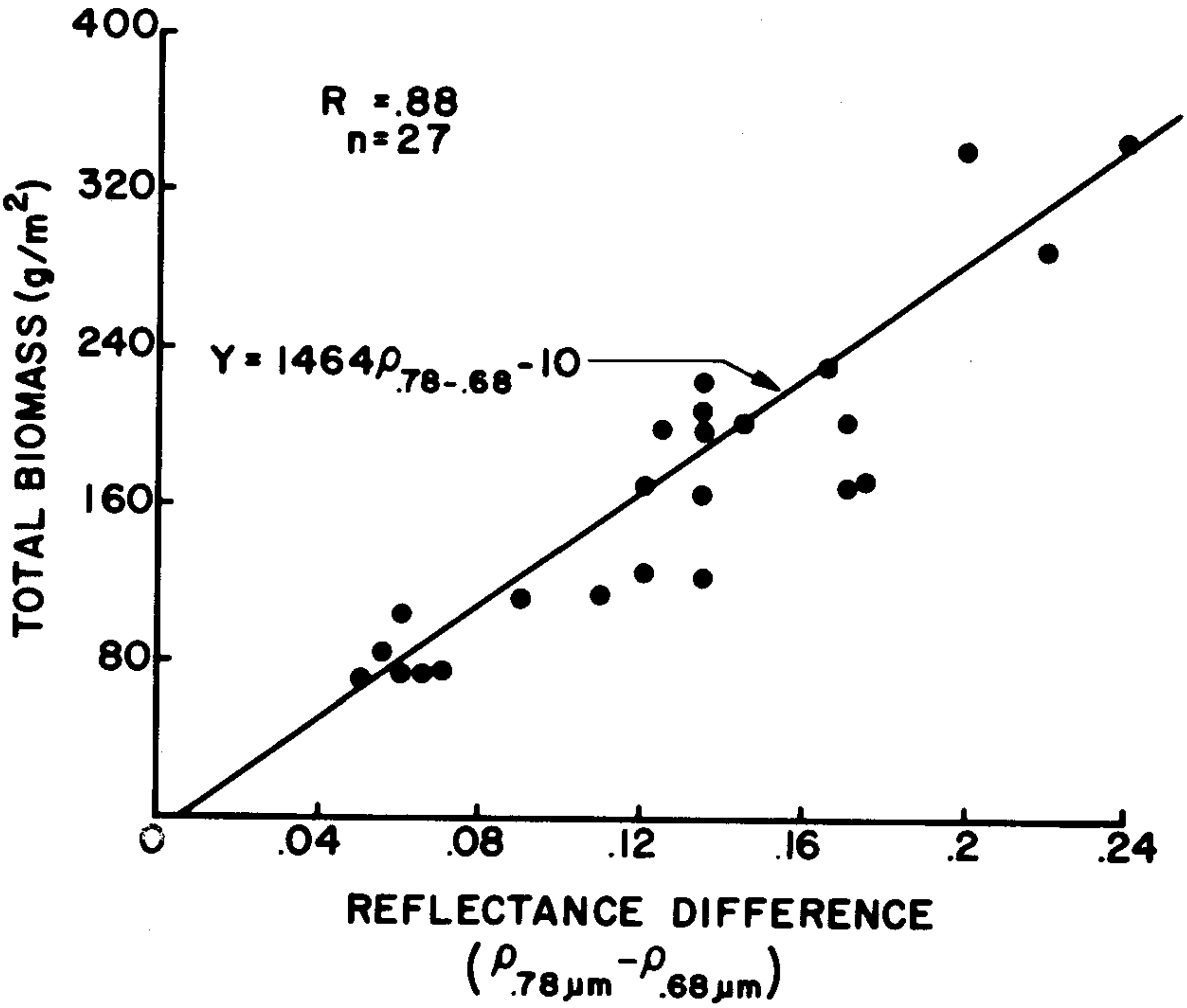


Fig. 16. Regression of the reflectance at .78 µm minus the reflectance at .68 µm (ρ.78 µm - ρ.68 µm) vs. total biomass for 27 undisturbed grassland plots (7000 to 7026).

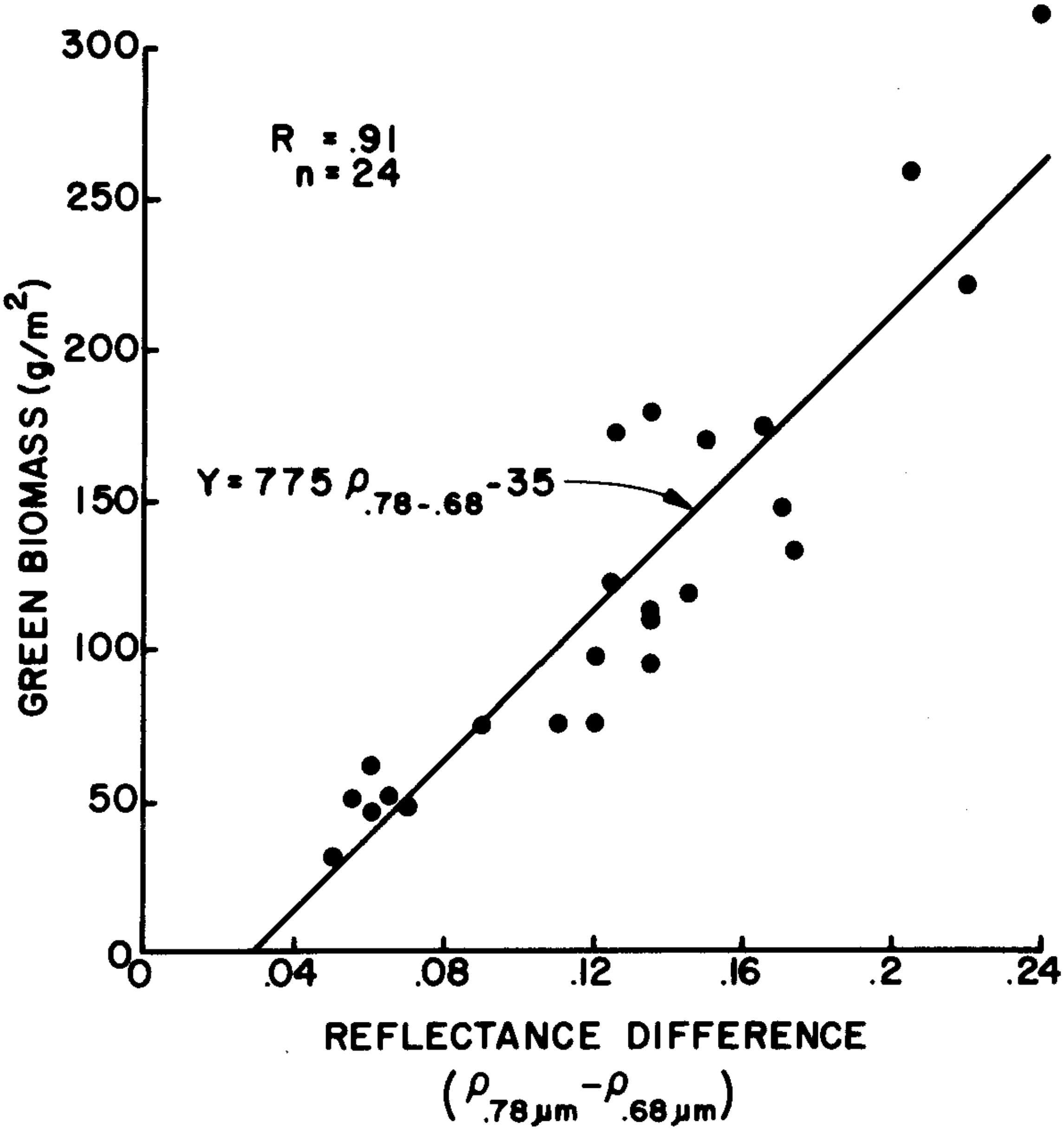


Fig. 17. Regression of the reflectance at .78 µm minus the reflectance at .68 µm (ρ.78 µm - ρ.68 µm) vs. green biomass for 24 undisturbed grassland plots. Three plots were removed from the original 27 of the series 7000-7026 due to missing green biomass data.

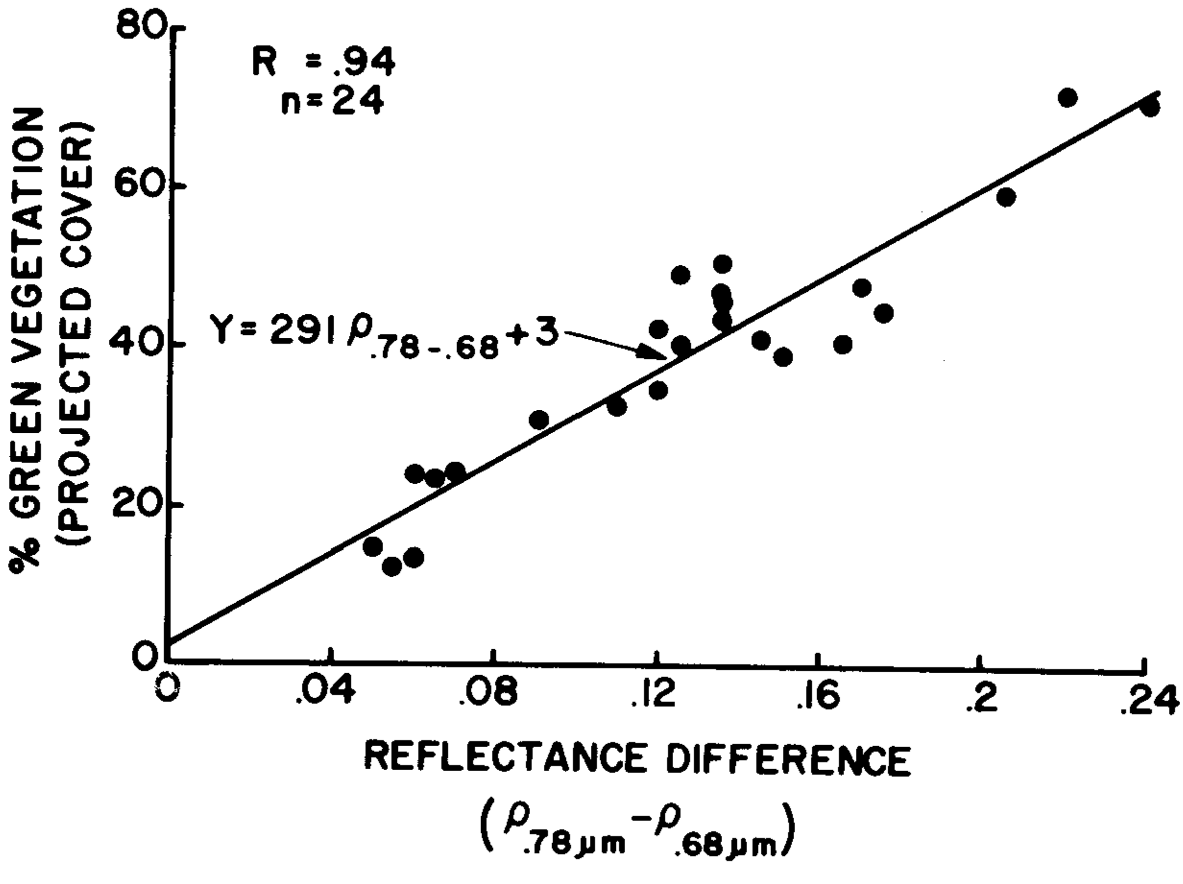


Fig. 18. Regression of the reflectance at .78 μm minus the reflectance at .68 μm ($\rho_{.78\ \mu m} - \rho_{.68\ \mu m}$) vs. projected green cover for 24 undisturbed grassland plots from the series 7000 to 7026. The projected green cover of each plot was determined by projecting the vertical color slide of the plot onto a 500-point grid.

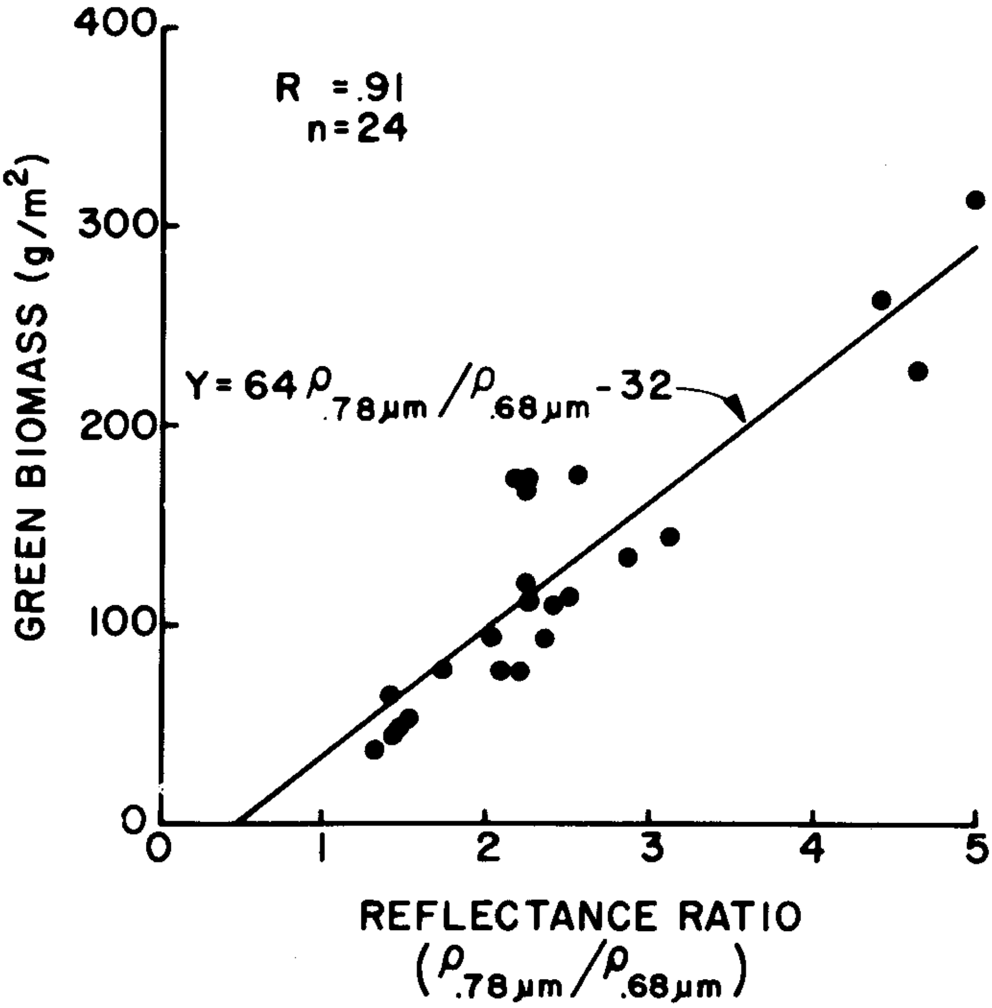


Fig. 19. Regression of the ratio of the reflectance at .78 μm to the reflectance at .68 μm (ρ.78 μm/ρ.68 μm) vs. green biomass for 24 of the undisturbed grassland plots (7000 to 7026).

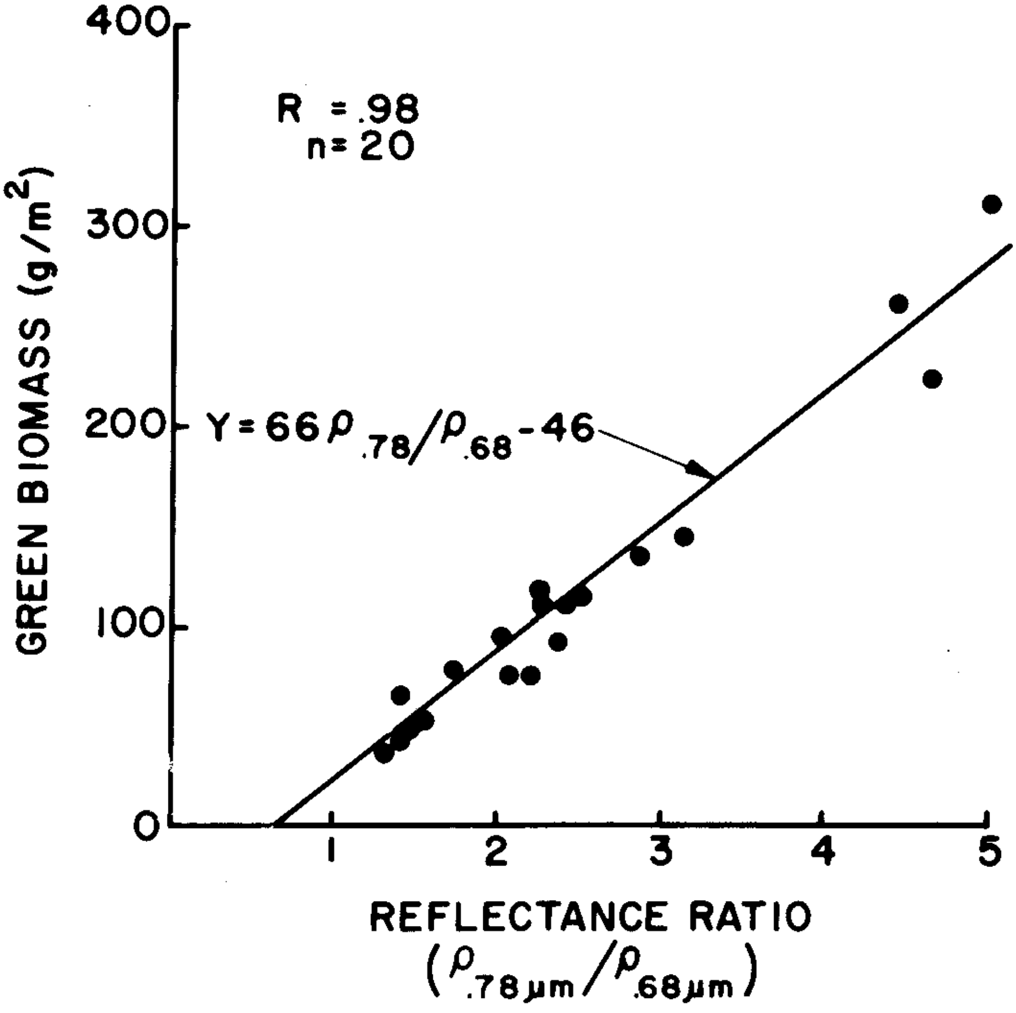


Fig. 20. Regression of the ratio of the reflectance at .78 μm to the reflectance at .68 μm (ρ.78 μm/ρ.68 μm) vs. green biomass for 20 undisturbed grassland plots (7000 to 7026). The four outlying points in Fig. 19 were removed before the calculation of this least-squares relationship.

These preliminary results show that the green biomass on a plot is highly correlated with the ratio of reflectance at .78 μm to that at .68 μm. Therefore, the scheme for simply and nondestructively measuring standing green biomass in the field can be based on this reflectance ratio. It can be shown that the ratio of the reflectance at .78 μm to the reflectance at .68 μm is approximately equal to the ratio of the radiance or the energy returned at these same wavelengths. This approximation holds if the ratio of the incident solar energy at .78 μm to the incident solar energy at .68 μm does not vary greatly (i.e., the spectral quality of the solar radiation does not change appreciably) which is the case on sunny days or under artificial illumination. The ratio of these two radiances from the vegetation is easily measured and is independent of the total level of incident irradiance (solar or artificial) for a first approximation. A simple device might thus be constructed to implement these radiance measurements. A discussion of the future plans for using this relationship is included later.

Radiance Under the Gas Analyzer Dome

The next experiment conducted by the field spectrometer during 1971 was the determination of the amount of spectroirradiance present beneath the plexiglass domes used by the field photosynthesis experiment of the Grassland Biome. This was accomplished by placing the viewing head of a fiber optics probe at the top of the grass canopy within the dome. The probe accepts total hemispherical irradiance within the dome according to a cosine function related to the vertical direction. This irradiance is conducted by the probe to the spectroradiometer situated on the ground just outside (Fig. 21). Solar irradiance in the dome was measured for one diurnal cycle (dawn to dusk), resulting in 60 visible band spectroirradiance curves (Fig. 22). The data obtained will be utilized for several determinations by the field photosynthesis experiment, one of which is the photometric

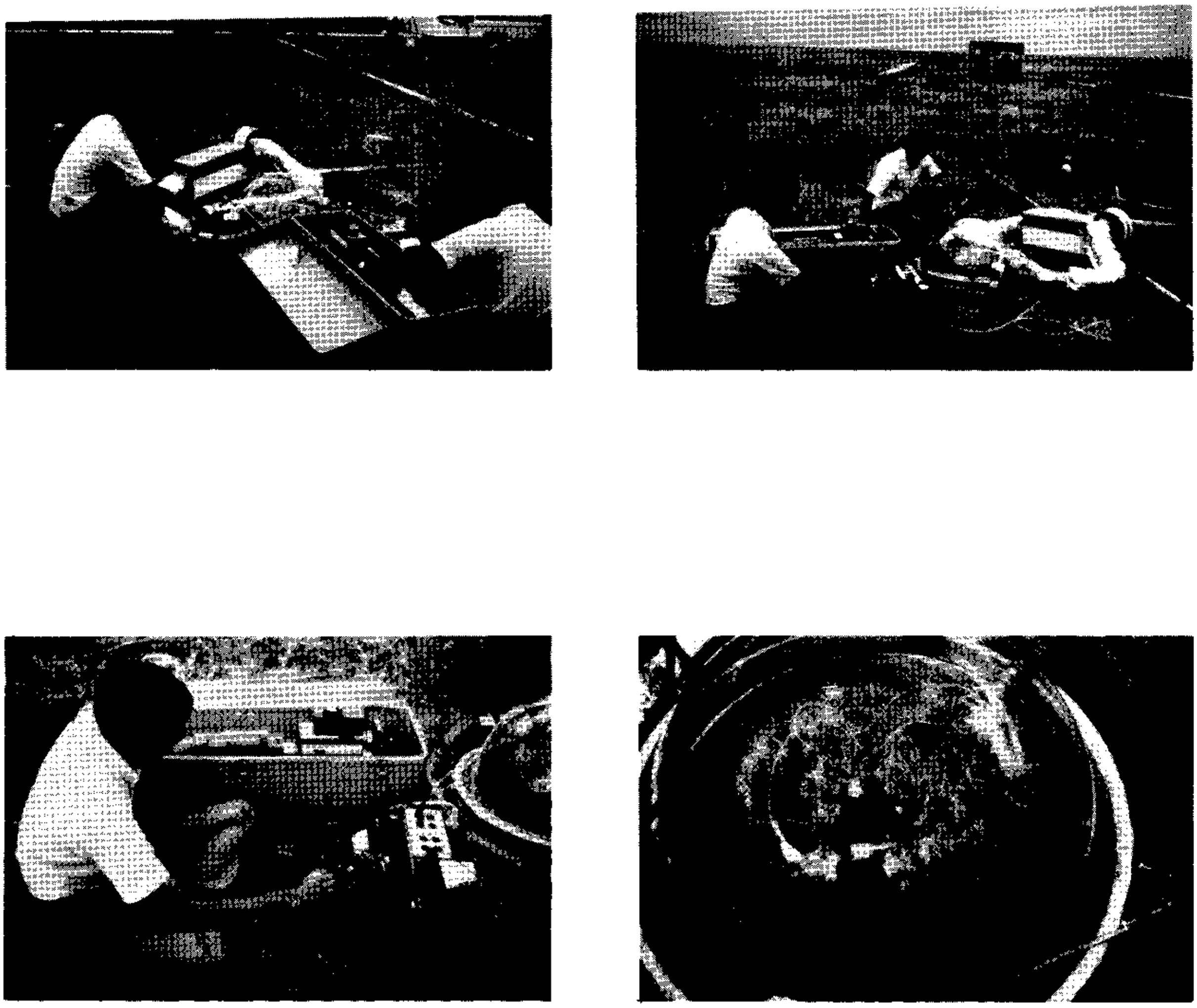


Fig. 21. Spectroirradiance determination under the gas analyzer dome. Note the plexiglass dome with the centered fiber optics probe beneath. The spectroradiometer is connected via data cable to the spectrometer laboratory (background).

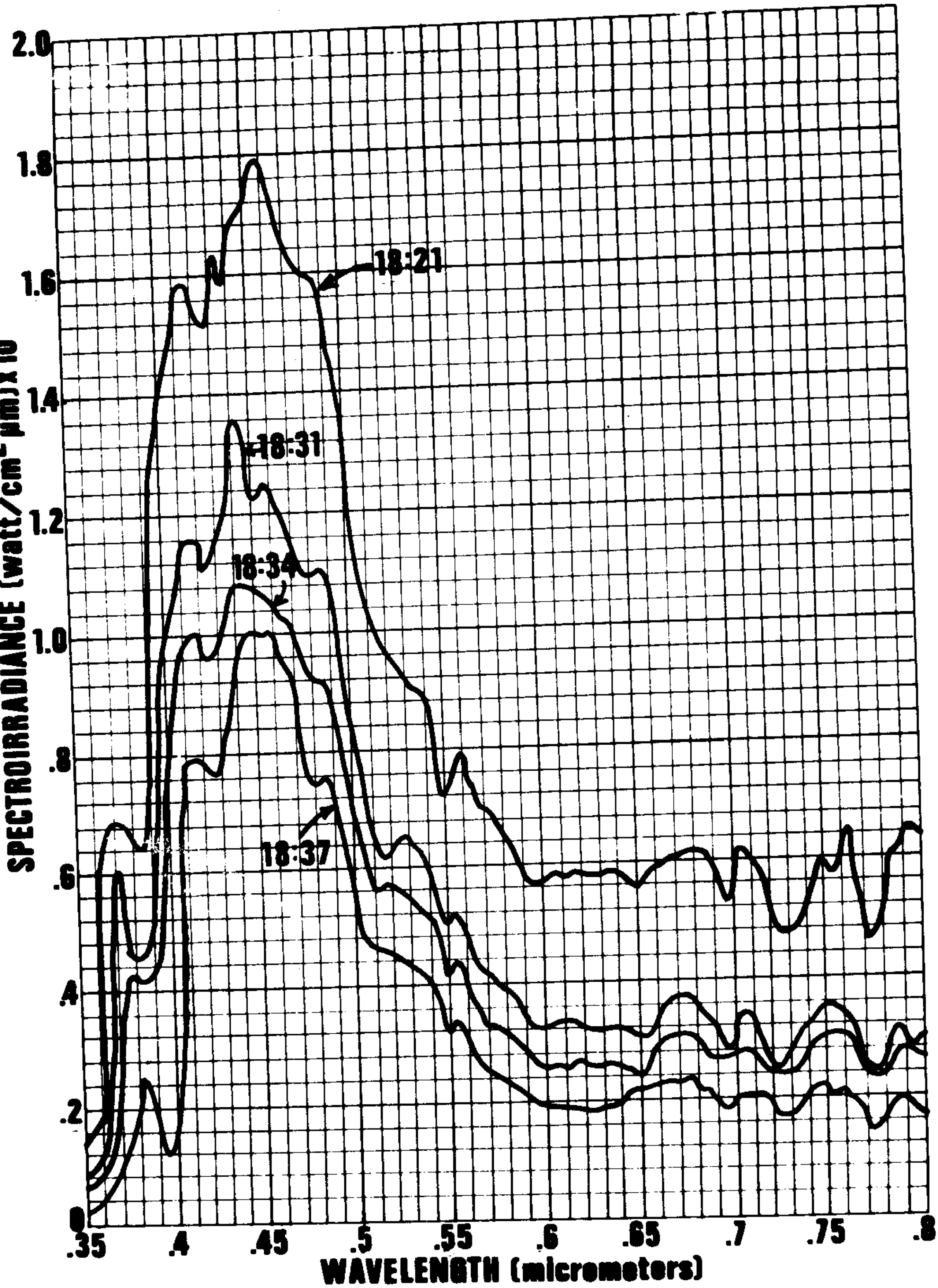


Fig. 22. Spectroirradiance curves taken under the gas analyzer dome and representative of the 60 measured during the day. The curves represent 16 min of elapsed time from 18:21 to 18:37 hr (MST) just before sunset when they varied markedly. Complete curves will occur in a subsequent data report.

calibration of the photocell normally used under the dome to measure the relative amount of sunlight reaching the plants enclosed.

Reflectance as a Function of the Time of Day

The final experiment for 1971 was on the change in spectroreflectance of natural grass plots under varying conditions of illumination. These conditions consisted of artificial and natural illumination for the same grassland plots at various times throughout the day. The results indicate that there was no significant change in spectroreflectance for natural illumination from one time of the day to another (Fig. 23). This reinforces an earlier assumption that the spectroreflectance of a grassland plot is relatively independent of the spectral quality or intensity of the illumination of that plot and that the normal spectroreflectance of short-grass prairie grasses does not change markedly over the course of a single day except in the effect created by shadows.

FUTURE PLANNED WORK

The anticipated work for the field spectrometer for 1972 is a continuation of the work done previously. Specifically planned are the construction and field testing of a prototype hand-held device for biomass determinations and the ground truth data acquisition for an anticipated 24-channel multispectral image overflight by NASA in mid-June. Also planned is the repetition of some of the past experiments to refine the results obtained to discover limiting conditions; that is, the significance of the difference in spectroreflectance of two plots, which are equal in total standing biomass but markedly different in green biomass, is not known.

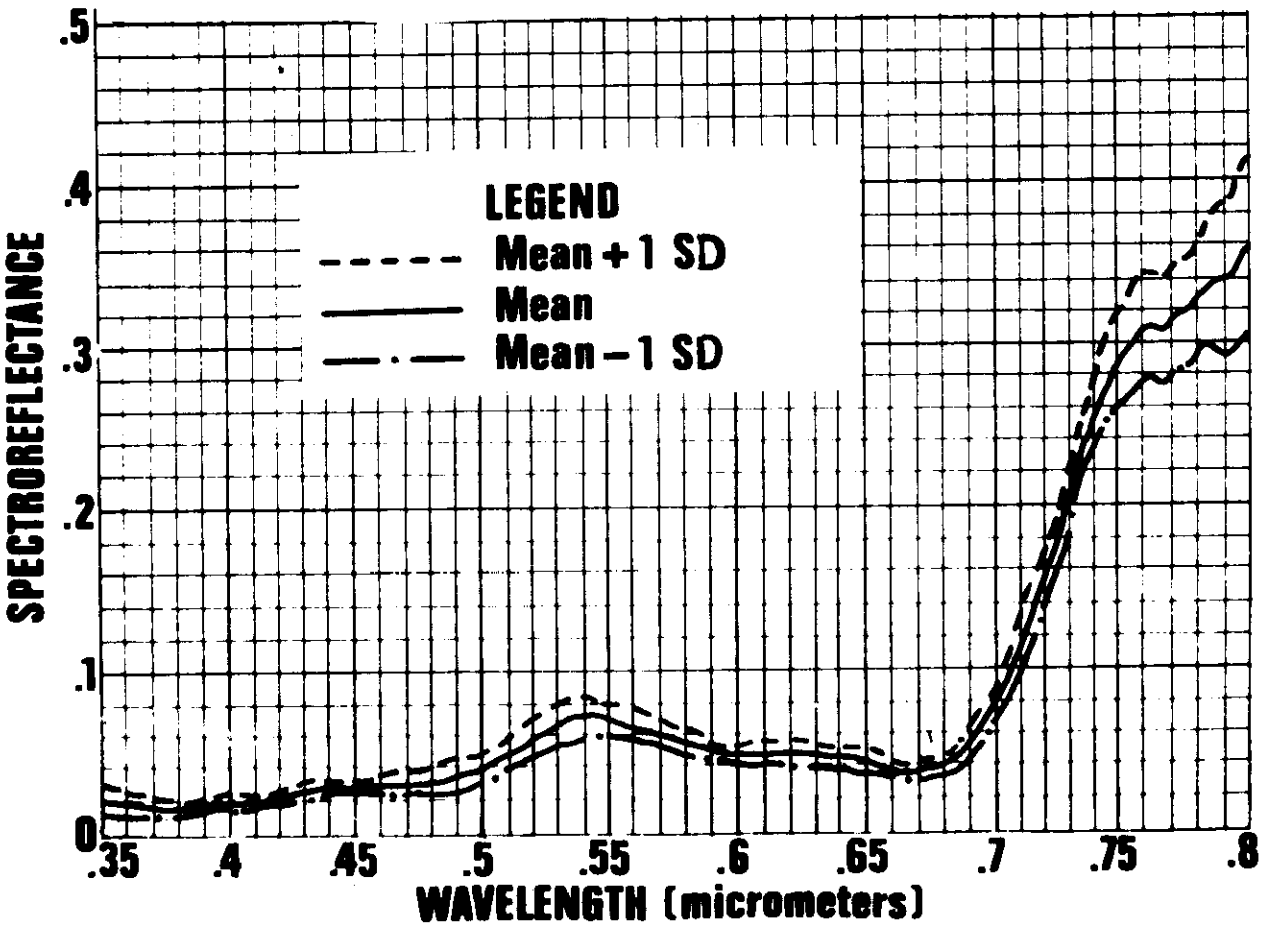


Fig. 23. Mean ± 1 SD of six spectroreflectance curves of one plot taken under natural illumination. The elapsed time period for these six curves is from 6:11 to 12:26 MST. The factors which varied most in the plot during this time were the amount and the position of shadows which accounts for the standard deviation shown.

The simple prototype model of the hand-held device as now envisioned will consist of a Cintra hand-held radiometer and associated components. The device will use two hand-held probes radiometrically precalibrated by Cintra which will operate in the two wavelength bands determined from the ¼ sq m plot experiments (.68 μm and .78 μm). The electrical outputs of the individual probes will be connected to a ratioing circuit which will divide the .78 μm radiance by the .68 μm radiance and display the result. This ratio, when adjusted by the proper constants determined by measurement of a few plots whose standing vegetation is clipped for biomass assay, will then be an estimate of the standing green biomass of the plots. This device will be used to measure the plots sampled for biomass by the IBP field crews. Then the estimates will be compared with the actual green biomass clipped from the plot to determine the accuracy of the method under field conditions.

Once the prototype device has been field proven during this next field season, the design of a simple, cheap production model can be undertaken to display the biomass or similar values directly. There are several different approaches which can be taken in the design of this final model. Therefore, the results of the field testing of a flexible prototype model must be evaluated before a decision on the final design can be made.

CONCLUSION

The data collected and results obtained during 1971 by the field spectrometer have shown a relationship between the spectroreflectance from a grassland plot and the amount of vegetation on that plot. This relationship is of considerable potential value in devising a method of nondestructive measurement of the cover and biomass in the shortgrass prairie ecosystem. The laboratory has also been shown to be valuable in the collection of spectroirradiance data which can be used by other experiments on the Pawnee Site.

ACKNOWLEDGMENTS

The personnel involved in maintaining and operating the laboratory during 1971 were: Dr. Lee D. Miller, principal investigator; Robert Pearson, principal graduate research assistant; Jim Tucker, Ralph Root, and Ghulam Ahmad, graduate research assistants; and Betty Clayton, Janice Ranson, Sharon Betz, and Janice Jameson, field assistants. Other investigators at the Pawnee Site who collected supporting data included: Dr. J. Trlica and A. J. Dye, light intensity and temperature; Dr. Dennis Knight, leaf area index; and Jim Hutcheson, leaf turgor pressure and leaf area index. As many as 12 people were in the field during intensive field sampling periods for several consecutive days, and at least four people (Dr. L. D. Miller, R. Pearson, J. Tucker, and B. Clayton) were in the field 12 hr/day for the 3-month period from June 15 through September 15.

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APPENDIX I

DATA LISTINGS AND PLOTTED SPECTRORADIANCE

Example data listings and plotted spectroradiance and spectroreflectance data curves of the 800 curve segments which will appear in a subsequent data report.

Sample Number	7023
Sample Description	"1/4 M PLT
Julian Date, Time	223,17,10
Number of Samples	91

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3600,	.4323E-07,	.1575E-08,
3650,	.4973E-07,	.1675E-08,
3700,	.5634E-07,	.1775E-08,
3750,	.5585E-07,	.1700E-08,
3800,	.5451E-07,	.6213E-08,
3850,	.1836E-06,	.7275E-08,
3900,	.2238E-06,	.8276E-08,
3950,	.2641E-06,	.9826E-08,
4000,	.3079E-06,	.1188E-07,
4050,	.3557E-06,	.1363E-07,
4100,	.4131E-06,	.1588E-07,
4150,	.4735E-06,	.1813E-07,
4200,	.5394E-06,	.2075E-07,
4250,	.6312E-06,	.2438E-07,
4300,	.7440E-06,	.2913E-07,
4350,	.8702E-06,	.3463E-07,
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4450,	.1222E-05,	.4813E-07,
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4750,	.2773E-05,	.1175E-06,
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4950,	.4055E-05,	.1830E-06,
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5700,	.5011E-05,	.3125E-06,
5750,	.5411E-05,	.3363E-06,

WAVELENGTH	WHITE PANEL RADIANCE	SAMPLE RADIANCE
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6100,	.4074E-05,	.2375E-06,
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WAVELENGTH	SAMPLE REFLECTANCE
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5450,	.6662E-01
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WAVELENGTH	SAMPLE REFLECTANCE
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6150,	.5813E-01
6200,	.5736E-01
6250,	.5710E-01
6300,	.5719E-01
6350,	.5691E-01
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6450,	.5625E-01
6500,	.5585E-01
6550,	.5536E-01
6600,	.5424E-01
6650,	.5435E-01
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6750,	.5402E-01
6800,	.5506E-01
6850,	.5795E-01
6900,	.6023E-01
6950,	.6554E-01
7000,	.7344E-01
7050,	.8427E-01
7100,	.9424E-01
7150,	.1087E+00
7200,	.1233E+00
7250,	.1408E+00
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7600,	.2356E+00
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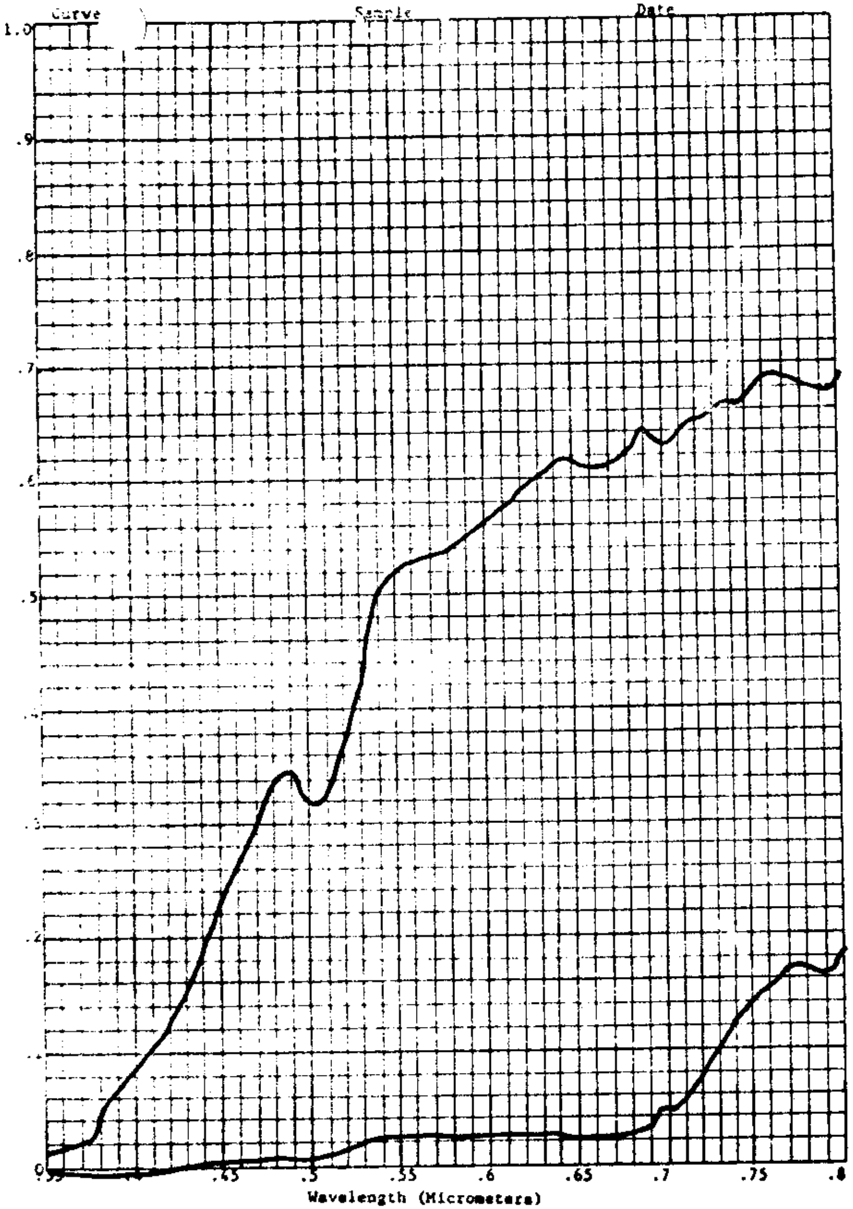
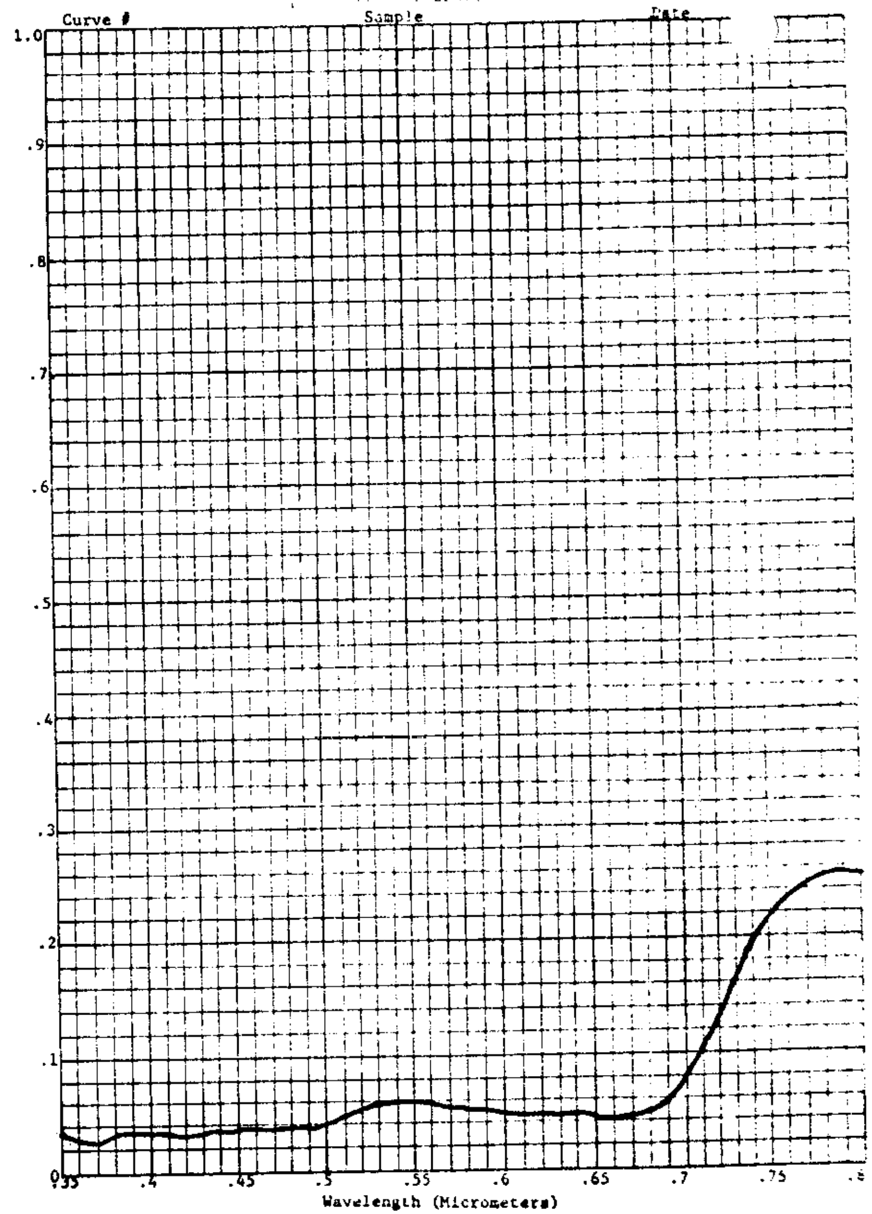


SPECTRORADIANCE CURVES
Max. Vert. Plot Value 0.1 w/cm² µm ster

VIEW OPTICS
Telescope X Fiber Optics Probe___
Field of View: 7.5'__, 15'__, 30' X, 1°__, 2° X
Slit Width: A X, B__, C__
Optical Filters:
UV 7-54__ VIS 7-54 X VIS 0-52 X VIS 3-69 X VIS 2-64 X IR 2-64__ IR 7-56__



SPECTROREFLECTANCE CURVES

CURVE NUMBER 7023
Description 1m² grass plot
Spectral Band UV___, VIS X, IR___
Location Pawnee irig. plots
Date: 223 Time: 17:10

SAMPLE
Illumination Type
Artificial X
Natural___
Angle of View 90°
Azmuth of View___
Solar Elevation___
Cloud Cover 50%