Technical Report No. 90

A FIELD LIGHT QUALITY LABORATORY--INITIAL EXPERIMENT: THE MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS BY REMOTE SENSING METHODOLOGY

Robert L. Pearson and Lee D. Miller

Department of Watershed Science
Colorado State University
Fort Collins, Colorado

and

K. Jon Ranson

Field Assistant
Department of Watershed Science
Colorado State University

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ABSTRACT

This technical report contains the progress report from January 1970 to January 1971 and the planning report for January 1971 through January 1972 for the Field Light Quality Laboratory of the Grassland Biome of the International Biological Program. Included in the report are descriptions of the lab design as well as the experimentation completed during 1970 which determined how well the lab responds to changes in percent cover of functioning green vegetation and the spectro-reflectances of some common grassland constituents in early October.

INTRODUCTION

This report concerns the Field Light Quality Laboratory Experiment funded by the U.S. International Biological Program Grassland Biome (IBP). The report details the activities and experiments carried out during 1970, the preliminary results obtained, and the planned work for the year 1971. The report also describes the equipment which was designed, purchased, and assembled for use in the experimentation.

OBJECTIVES

The purpose of this investigation is to develop a rapid, nondestructive method for sampling the sparse vegetation of a short grass prairie. The background information of these preliminary phases must be suitable for the subsequent development of rapid, low cost measurements using either portable "plot sized" equipment or airborne sensors for satellite mounted equipment.

General Approach

The system, as developed, will measure *in situ* reflectivity of field plots from 10 cm to 3 mm in diameter, allowing the study of individual grass leaves, a grass clump, or a larger area of a plot. Also, the basic wavelength range of operation is in the biologically important region from .18 to 1.6 microns (ultraviolet to near infrared), a broad spectral range from which to select optimum wavelength bands for determination of percent cover of green vegetation.

The operation of the lab as a tool for determination of percent cover requires that calibration spectroreflectance curves of each of the constituent components are known when observing curves for composite sample plots. Initially, it was decided to obtain these calibration curves by looking at each component (dead grass blades, live grass blades, and soil) separately and obtaining their calibration spectroreflectances directly. However, these calibration curves can also be obtained by determining percent cover of several plots using traditional point quadrate or photographic methods.[1/] The spectroreflectance of these same sample plots is measured with the instrument. Finally, a family of simultaneous equations is solved using the composite curves, and the known cover values are used to obtain the calibration spectra for the different materials making up the plot. These calibration spectra are then used with new composite spectra elsewhere in the same grass type to determine percent cover of the major materials in unknown plots.

This method has several advantages. First, less field time and effort is required because at no time is each individual component viewed separately. Rather, the composite area is viewed by two different methods (i.e., spectroradiometric and photographic, or point quadrate). Since the need for viewing individual components is eliminated, the method can be used without having to be close to the scene. The value of this advantage becomes apparent when one anticipates subsequent aircraft spectrometer use of the principle rather than ground operation. A more complete description of the revised method is included in the experiment portion of this report.

[1/] A separate report will be issued describing the photographic method for measuring percent cover.

LABORATORY DESIGN

The basic field laboratory is a small house trailer containing the spectroradiometer, a computerized data acquisition and control system, x-y plotter for on line spectroreflectance display, a portable power generator, and other logistical support equipment. In the primary mode of operation, the equipment is connected so that the data flows from the spectroradiometer through the computer to the x-y plotter and the paper tape punch (Fig. 1). The lab is designed so that the spectroradiometer and any other data collectors (e.g., anemometers, thermisters, heat flux cells, etc.) can be controlled and measured from inside the trailer by the computing system or they can be up to 90 m away from the trailer and connected to the system

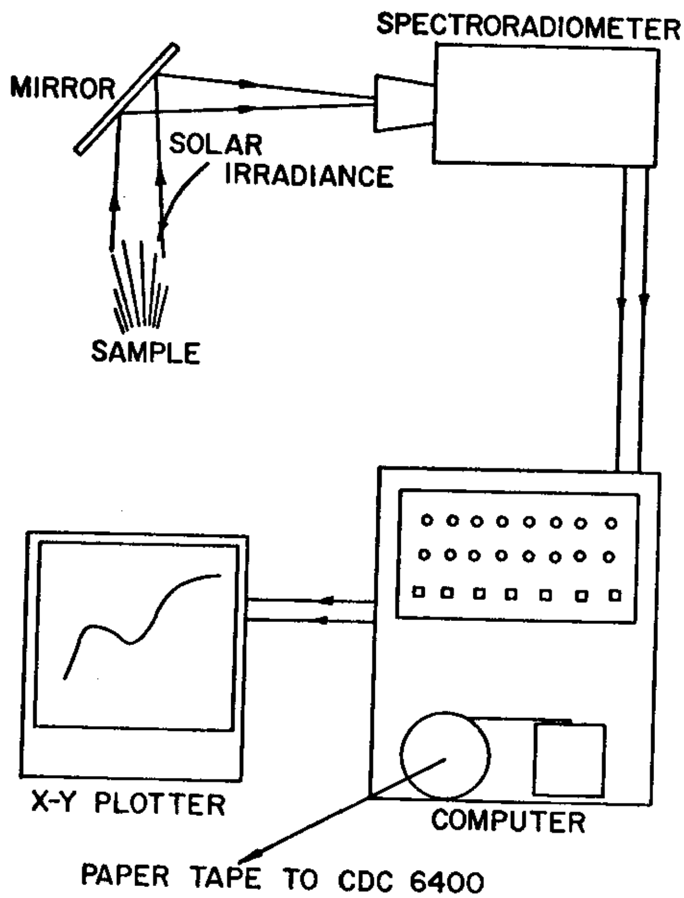


Fig. 1. Diagram of data flow through the light laboratory.

by means of a multi-conductor geophysical-type data cable functioning as an umbilical cord in supplying AC power and the data collection lines.

The field trailer is a 13½ foot camping trailer (Fig. 2). It contains a work counter at the rear for the spectroradiometer, a platform for the computer data acquisition system, an area in the front for the computer's teletype, and numerous special storage cabinets and closets for small pieces of equipment. The large 11,000 BTU per hour air conditioning unit is used to maintain air flow from the interior of the trailer to the outside so that dust seepage into the trailer will be minimized during operations in the summer on the windy prairie. Both the spectroradiometer and the computer system are sensitive to dust and temperatures in excess of 80°F. Therefore, the air conditioner and heater are used to maintain the interior temperature of the trailer at approximately 72°F during operation.

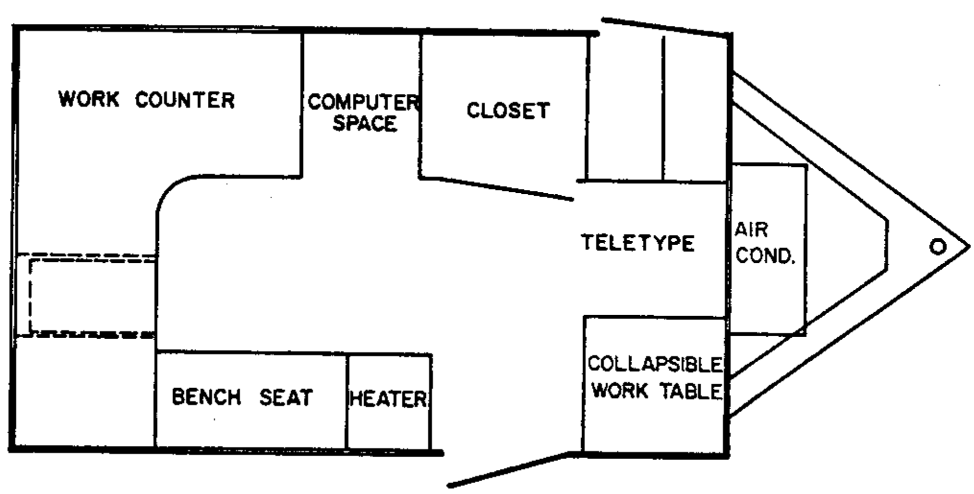


Fig. 2. Floor plan of the interior of the laboratory trailer.

The spectroradiometer system consists of a telescope module with a field of view variable from 2° to 7.5' which looks out a styrofoam insert in the trailer's side; a monochromator module which contains the dispersion grating; atop the monochromator, a wavelength transducer which yields an electrical voltage proportional to the wavelength being sampled; a detector module containing the detector head which measures the level of light at the specific wavelength; and an indicator unit which contains the range selection switches and the readout meter for the detector head. The system has three different gratings and two separate detector modules to cover the wavelength interval from .18 to 1.6μ. The system can also be operated with a fibre optics probe replacing the telescope so that very small areas or difficult viewing angles can be measured. The spectroradiometer was to be removed from the trailer when this 1 m probe was used, housed in a large fiberglass box, taken to the sample position, and connected to the remote operation umbilical cord. We have not yet solved the problem of taking the instrument into the exterior environment with its attendant rise in temperature. It may be necessary to air condition the fiberglass box for this mode of operation.

Because of the large quantities of data generated by a spectroradiometer and the need to use it in the field as a spectrophotometer, a computerized data acquisition system is used to control the experiment, collect the data, make initial field computation and display the resulting curves. This Hewlett-Packard system consists of: a 2114A digital computer with an 8000 word memory with a 16 bit word size; a high speed (10 khz), low-level (down to 10 mv full scale) multiplexer and analog to a digital converter; and a teletype for communication with the computer. Inside the computer is a crystal controlled time base generator and a digital to analog output card which allows online data dump onto the 11 inch by 17 inch x-y plotter.

A computerized data acquisition system was chosen because of its extreme flexibility. The analog to digital conversion input system will accept 56 more analog data channels by simply plugging in a connector card, and an upper limit of up to 556 channels could be used with the purchase of additional multiplexers. The computer itself will accept up to 26 more peripheral devices using the multiplexed Input-Output option including a disk, read-write magnetic tape units, relay closure output cards to control numerous other pieces of external equipment, and several other peripheral devices. In short, just about any electronic equipment can be connected to and be controlled by this system and yet it was no more expensive than a good high speed data acquisition offered by the same manufacturer.

The software which the computer uses can be written in any of four languages (FORTRAN, ALGOL, Basic, and Assembler). The 8000 word memory size allows our programs to control the experiment and processes raw data held resident in memory. With the addition of a magnetic tape operating system, much larger and more complex programs could be segmented and run than are now currently possible by using a memory overlay technique.

At the present time, the data out of the system is presented in three ways. The teletype, acting as a control device, allows the presentation of tabularized data and results for immediate review. The inexpensive (compared to magnetic tapes) high speed punch creates a computer compatable record which can be used as input for further data analysis and reduction. The current drawback with the paper tape as an input medium to CSU's 6400 Central CDC is that the Computer Center can presently only read paper tape through a teletype at 10 characters per second, as they have no high speed paper tape reader. At that rate, it would take us 37 minutes to read a complete spectral curve for one test object into the central computer, six times the time it takes to collect it in the field. The third output method currently being completed is from the computer directly onto the x-y plotter, which allows an on-line graphic display of the spectroreflectivity data. This allows us to determine, as the curves are being collected, whether they appear correct and adjust our procedure if they do not.

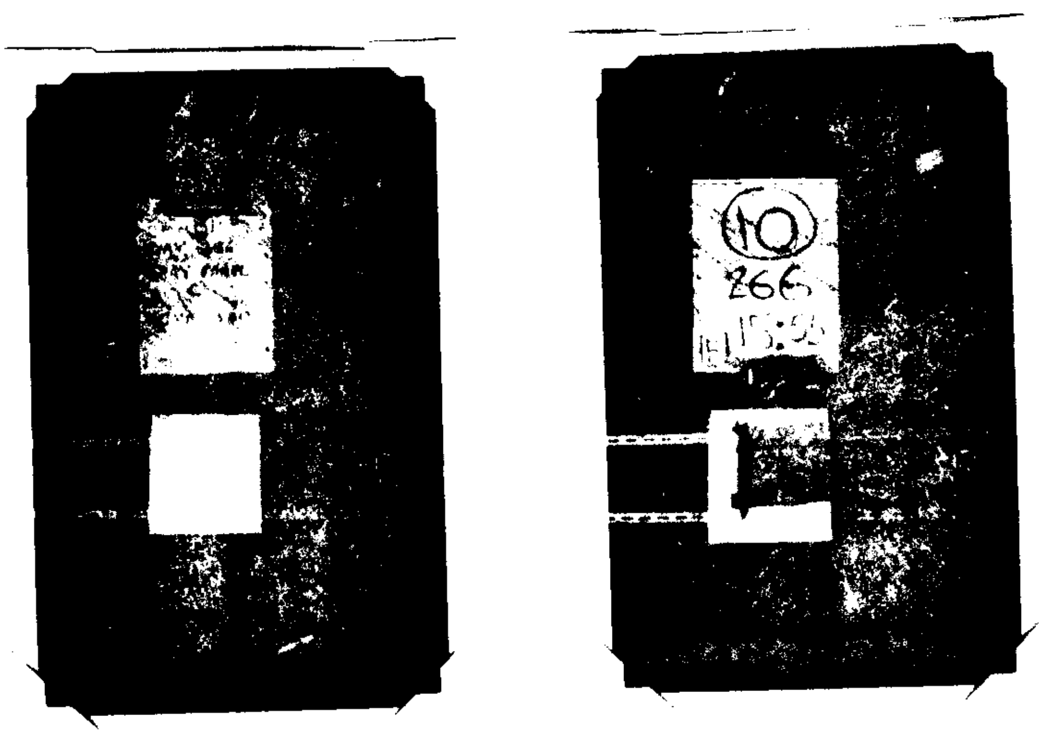
OPERATIONAL PROCEDURE

The basic mode of operation of this system is to first view a white, barium sulphate coated panel placed on the ground next to the sample plot to be measured. $BaSO_4$ is an almost perfect Lambertian reflector which, when viewed, allows the determination of the incoming solar curve as a function of wavelength (spectral irradiance). The panel is then removed, and the spectral radiance curve from the sample plot is read by the spectroradiometer. Both of the sets of data are read into the computer on a wavelength basis as they are obtained. The computer ratios the spectral radiance from the sample plot at a particular angle to that from the reference standard as a function of wavelength and displays the results in the three output forms described above. A more detailed description of the operation can be obtained from Miller and Pearson (1969).

EXPERIMENTATION PERFORMED DURING 1970

Spectroreflectance of Test Panels

A series of tests were run to assess how the experimental method and the instrumentation compared to laboratory type spectrophotometers. Special Data Corporation canvas reflectance panels were chosen as samples because of their stability, ease of handling, and availability. Initially, the panels were measured by the field spectroradiometer using the method described above in the wavelength region from .4 to 1.6μ (Fig. 3). Next, these same panels were measured on a laboratory Perkin-Elmer spectrophotometer over the same wavelength interval. The infrared portion of the field collected curves has not been included because the results were affected by an accident to the



(a) $BaSO_4$ coated reference panel.

(b) Gray canvas panel.

Fig. 3. Measurement setups for obtaining field curve for a canvas panel to be remeasured in a laboratory spectrophotometer.

spectroradiometer. However, the instrument has been returned from the factory after repair and recalibration and should be ready for testing again around January 1, 1971.

This preliminary comparison of the reflectance curves obtained with the conventional laboratory spectrophotometer and our field system shows that both yield essentially the same curves for the test panels in the visible region (Fig. 4). A more definitive comparison of this type will be rerun with the total wavelength interval available using canvas panels of various levels of reflectivity and various other solid materials which can similarly be measured in the field and the laboratory.

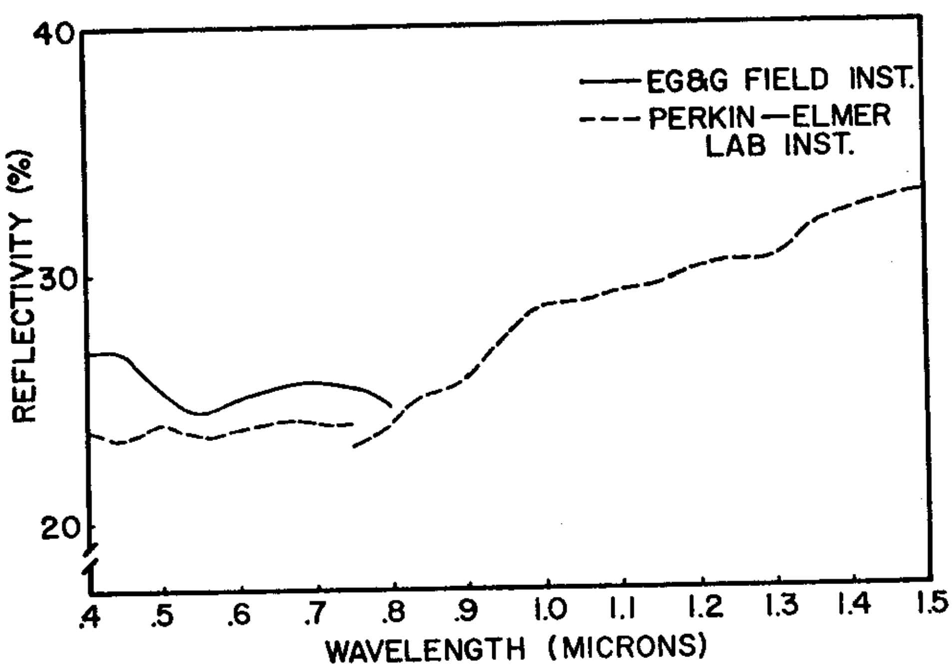


Fig. 4. Diagram showing the comparison of canvas panel curves measured by our field system and a Perkin-Elmer laboratory spectrophotometer.

Spectroreflectance of *In Situ* Grassland Constituents

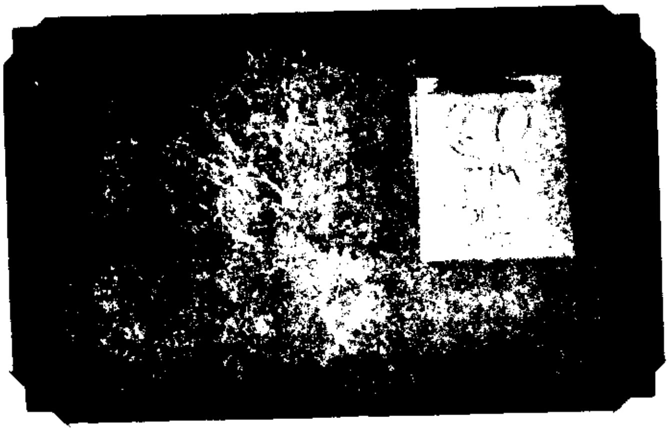
The second preliminary test experiment performed during the year was to determine how effectively the field spectrometer in its initial configuration could be used to catalog spectroreflectance curves for several constituents of the grassland including both vegetation and soil. Fig. 5 contains photographs of the plant and soil samples as they appeared when measured. The wire ring in each photograph denotes the field of view of the spectroradiometer when the curves were measured, and the numbers on the clipboard are, from top to bottom: a sample reference number (encircled), the Julian date of the experiment, and the Mountain Standard Time of the readings.

These photographs clearly show the reason for the differences which should be expected between laboratory and field spectroreflectance curves of natural materials. Laboratory measurements of the vegetation in Fig. 5 could be made for both the yellow inflorescence and the green leaf and stem material. Yet, it would be difficult to construct the composite *in situ* spectroreflectance of the plant from these measurements, and it is these spectral functions which determine the amount and spectral distribution of solar energy flowing into the ecosystem through its plants, soils, and animals.

(a) Sample 25. *Chrysothamnus nauseosus* (Rabbitbrush) at 1200 hours MST.

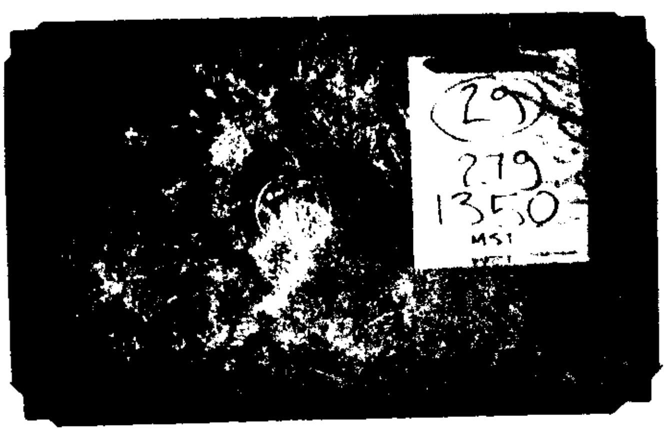
(b) Sample 26. *Eriogonum microthecium* (Buckwheat) at 1245 hours MST.

Fig. 5. Photographs showing sample grassland plants and soil as they were measured by the light quality laboratory on October 3, 1970. The area within the wire ring was the actual sample area viewed by the spectroradiometer.



(c) Sample 27. *Aristida longiseta* (Red threeawn) at 1300 hours MST.

(d) Sample 28. Ascalon sandy loam soil at 1315 hours MST.



(e) Sample 29. *Opuntia humifusa* (Pricklypear cactus) at 1350 hours MST.

(f) Sample 31. *Artemisia* (sagebrush) at 1455 hours MST.

Fig. 5. (Continued)

The preliminary curves obtained (Fig. 6) were taken primarily to test the instrumentation and should not be relied upon for significant interpretation. We propose to measure an annual sequence of such curves at different periods during the next growing year over the interval of .35 to 1.2μ for each of the major vegetation and soil constituents present on the Pawnee Site. We also plan to obtain sufficient spectral measurements of the solar incoming to the site over the same wavelength intervals so that the flow of energy into the ecosystem and several of its major components can be accurately determined on a day by day or week by week basis.

The curves do clearly show that the differences in spectroreflectance between various species can amount from 2% to 25% in some cases. These differences can be used to differentiate between the species from an aerial measurement viewpoint with colored films and more sophisticated remote sensors. These differences also show that defining the solar energy flow into a highly accurate energy model by a time continuous measurement of the total incoming solar energy times an average albedo for grasslands could be in error by as much as 10%. A much better energy flux model of incoming energy can be prepared on a component by component basis using similar spectroreflectance curves and spectral measurements of solar incoming at various times throughout the season. The time continuous total solar incoming measurements taken at the meteorological trailer will serve as an aid in interpolating these intermittant spectrometer measurements.

Feasibility Experiment for the Measurement of Percent Cover

The third experiment was intended to determine the response of the spectroradiometer to changes in percentage of grass in the field of view. A

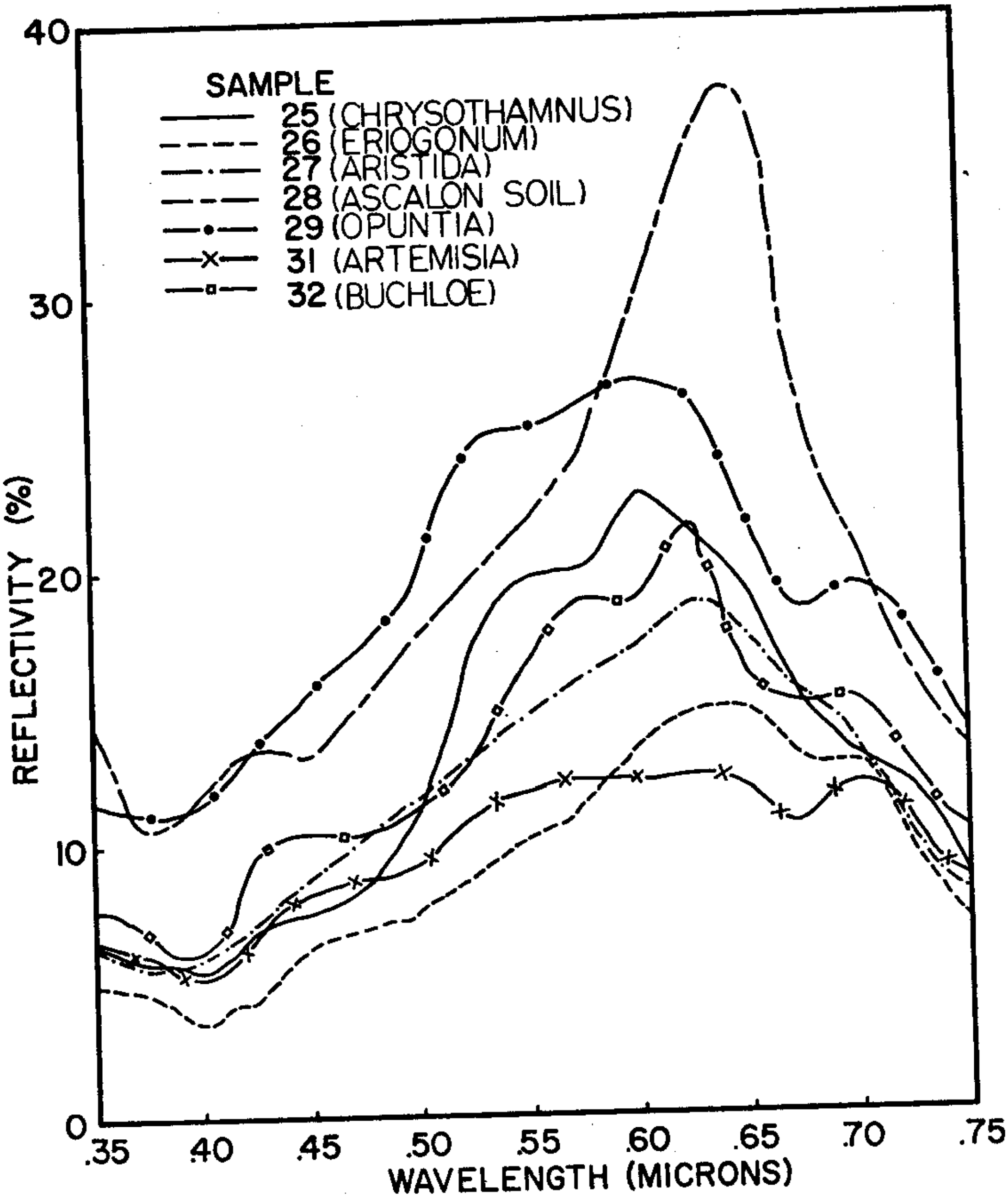


Fig. 6. Spectroreflectance curves for several types of vegetation and soil on the Pawnee Intensive Site collected October 3, 1970; all measurements made normal to the underlying soil surface.

dense clump of blue grama sod, approximating 100% cover, was placed on a movable cart underneath the tripod-mounted folding mirror (Fig. 7). The area under and adjacent to the sod was covered by soil from the same area. The cart was then situated so that, when it was moved, the spectroradiometer "looked" at either soil or grass or part of each at the boundary between. The actual percentage of the vegetation and soil seen by the spectroradiometer in each setup was calculated from the geometry of the particular arrangement. The spectroradiometer output was plotted directly onto the x-y plotter for each setup of different grass and soil amounts (Fig. 8). These

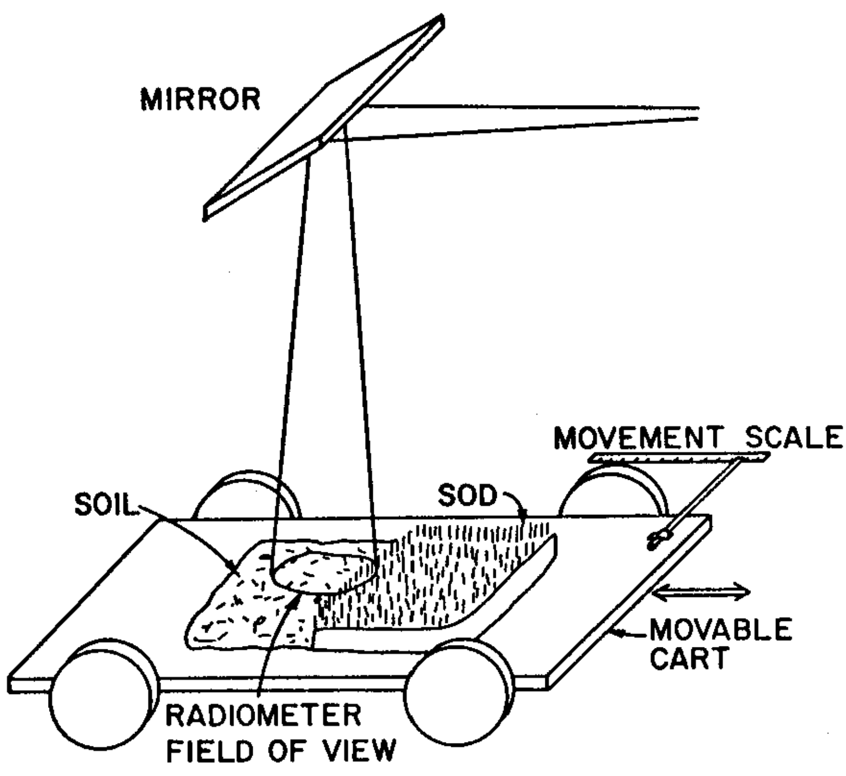


Fig. 7. Diagram of cart arrangement used in the preliminary experiment to determine percent cover.

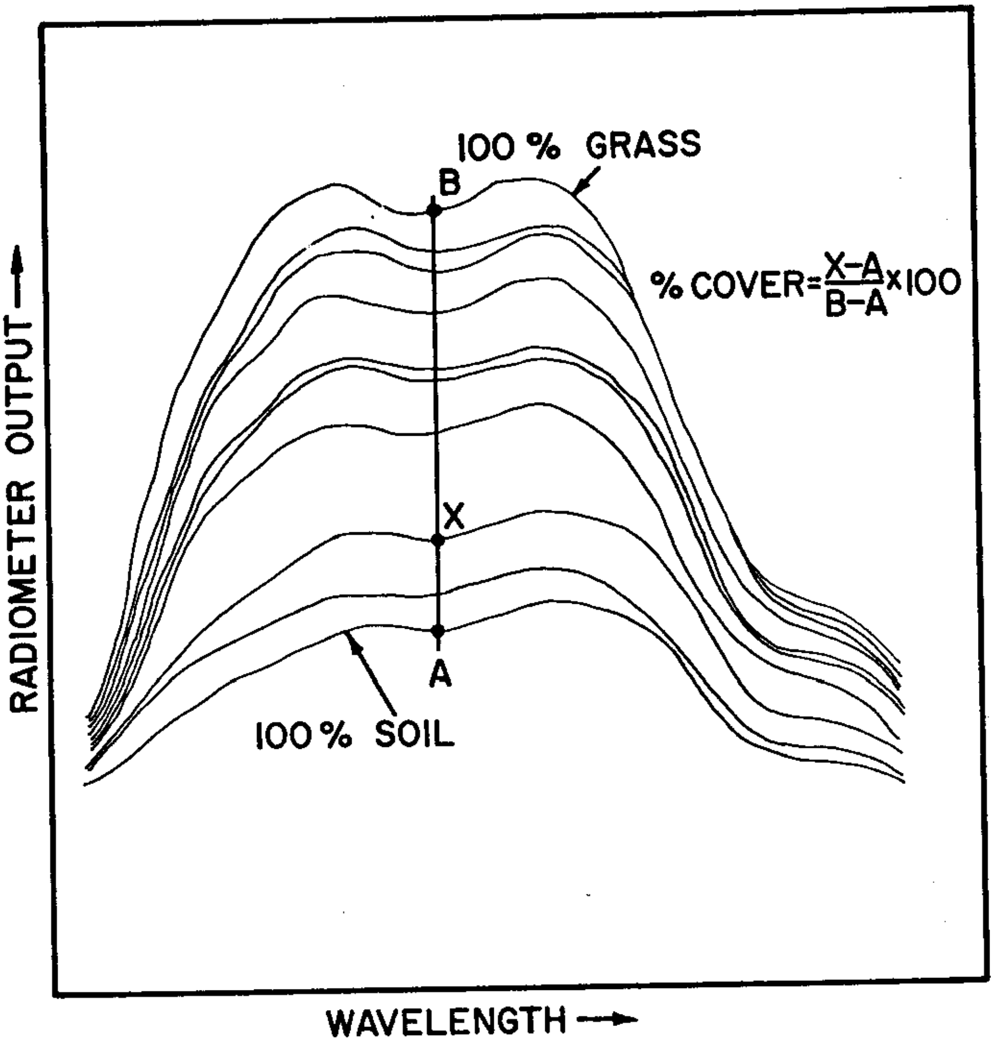


Fig. 8. Uncorrected radiometer data from simple cover experiment.

curves represent the spectral radiance from the sample multiplied by the spectral detector function of this instrument. Since the detector curve is only a wavelength function, it cancels out in the ratios to be taken. Limiting curves were obtained for 100% sod or grass and for 100% exposed soil. Using these limiting curves, a percent cover of green vegetation versus soils for the intermediate setups can be computed at each wavelength using:

$$P\lambda = \frac{X\lambda - A\lambda}{B\lambda - A\lambda} \ (100),$$

where $P\lambda$ = percentage of green vegetation versus soil computed at wavelength λ,

$X\lambda$ = spectroradiometer output from the unknown sample at λ,

$A\lambda$ = spectroradiometer output from 100% soil sample at λ,

and $B\lambda$ = spectroradiometer output from 100% grass samples at λ.

This equation was solved for all wavelengths on each intermediate curve for .7 to 1.0μ representing different amounts of grass and soil. These curves of percent cover, computed as a function of wavelength, can then be compared with the known amounts of cover computed from the setup geometry (Fig. 9). The two sets of curves agree reasonably well, and the error that exists can be explained by the irregular boundary between the sod and the soil and the crude scheme for measuring the position of the cart which had a standard error of roughly 2 cm. Variation in the computed percent cover curve for a fixed amount of vegetation and soil with wavelength is obtained in this computation (Fig. 9). Subsequently, we intend to interpret this information to determine the most accurate, single wavelength at which to make simple measurements with simpler instruments for percent cover in a particular vegetation-soil type. This data from our first shake-down exercise is not particularly

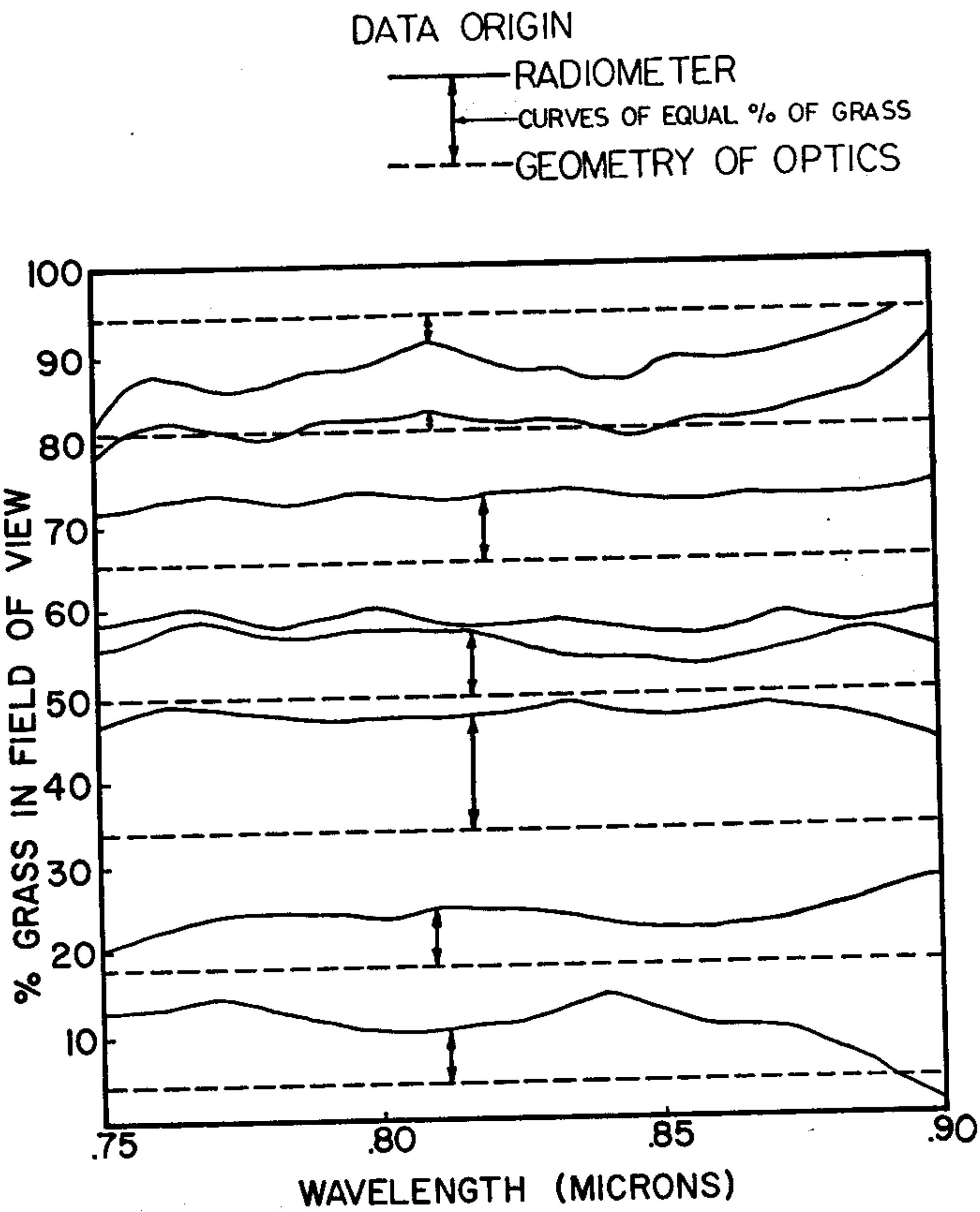


Fig. 9. Comparison of the computed vs measured amounts of grass vs soil.

useful for this purpose. The main conclusion of this preliminary, simple experiment is that spectroradiance and spectroreflectance clearly do reflect changes in the percentage of grass and can be measured with our instrument. How well and how accurately this can be done will have to be determined during subsequent experimentation.

Measurement of Reflectance Curves for Complex Views of Soil, Live Grasses, and Dead Grasses

The fourth and most complex experiment was to determine the spectral reflectance of several natural soil-grass plots. The area chosen was near the headquarters building of the Pawnee Intensive Site and consisted of several 8 cm diameter circular plots of various ratios of soil to grass and dead vegetation. The spectral reflectivity normal to each plot was determined from the spectroradiometer output measured within the space of two hours (Fig. 10). Then photographs were taken of the plots with both color (Fig. 11) and color infrared film. The percentage of each of the components was determined by projecting the color infrared image onto a dot grid and counting the number of dots touching each component (Table 1).[2/] We are currently in the process of evaluating the reflectance curves for these complex fields of view in comparison to the known amounts of projected area cover for the various constituents present and measured by the photographic method.

Spectral Transmission of the Grassland Photosynthesis Domes

The last experiment performed by the laboratory before it was dismantled for the winter was the determination of the spectral transmission of the plexiglass gas analyser domes used by the photosynthesis group. In this exercise,

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[2/] See forthcoming IBP technical report for technique.

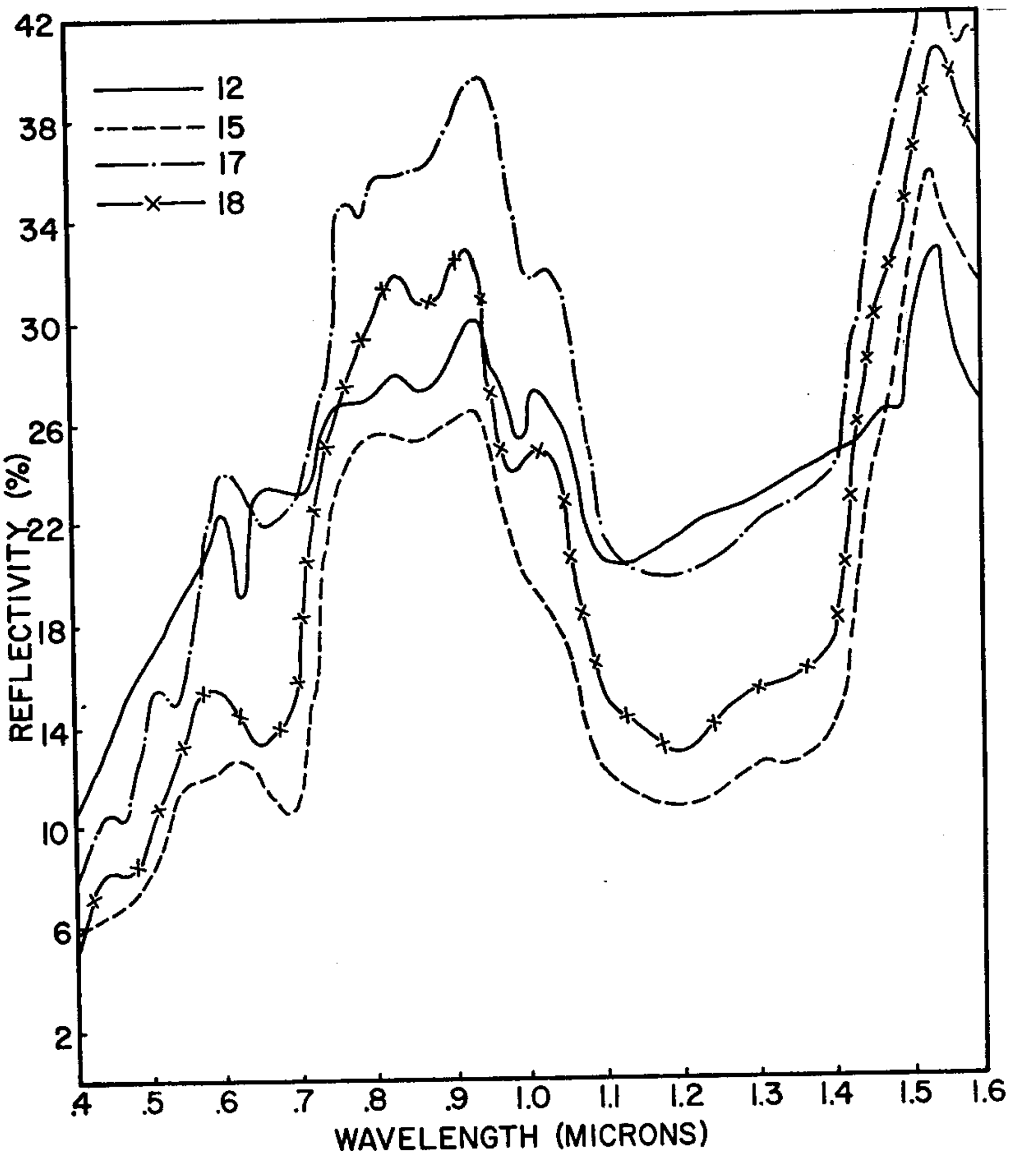
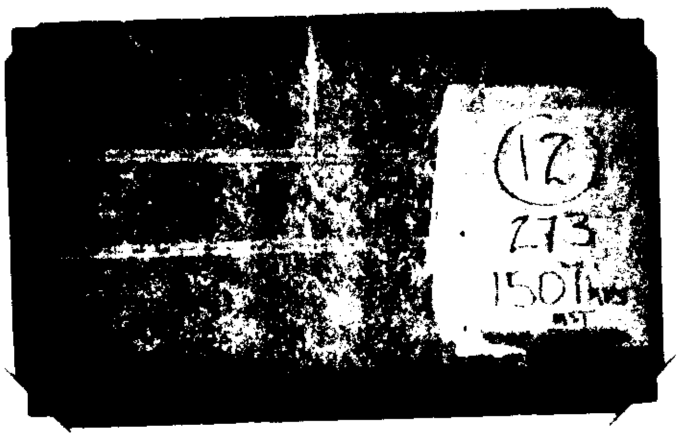
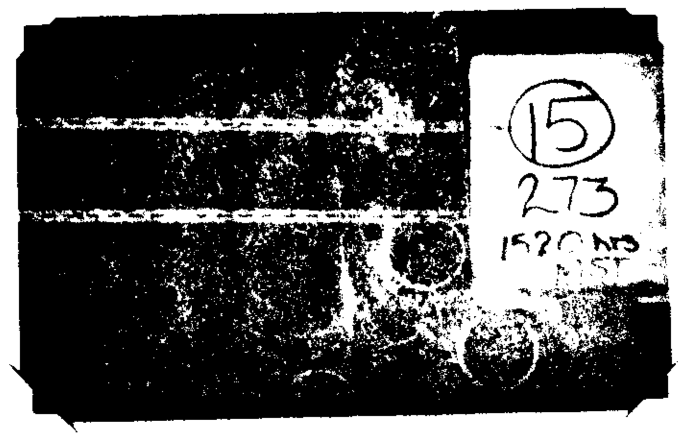


Fig. 10. Spectroreflectivity of four of the 8 cm diameter natural grassland plots. (See Table 1 for relative amounts of constituent components in each plot.)

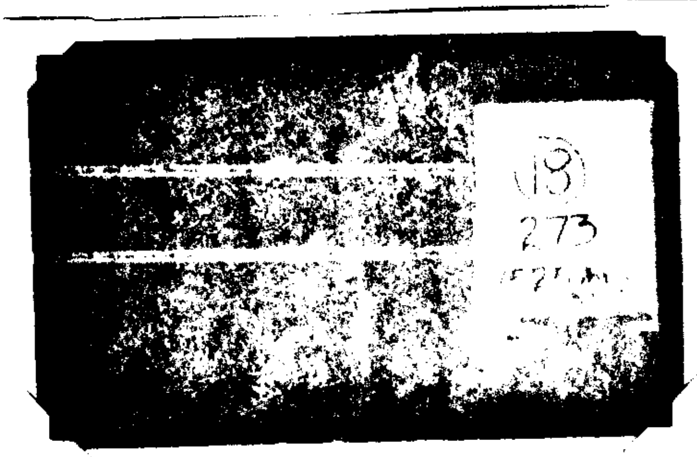


(a)



(b)

(c)



(d)

Fig. 11. Four of the individual 8 cm sample plots. The actual area is circular and tangent to and between the two aluminum rods at the point of the pencil laid on the ground.

Table 1. Vertical projected cover measured from Ektachrome I.R. taken September 30, 1970.

Sample No.	12	15		17		18	
	Values in Percent						
Green Vegetation	-0	11.1		8.7		11.2	
Partially Green	-0	19.0	32.7	2.2	12.4	21.5	37.4
Intermediate	-0	2.6		1.5		4.7	
Mostly Dead	-0	1.4	19.5	0.4	8.9	0.4	15.0
Dead Vegetation	-0	18.1		8.5		14.6	
Shadows	-34	37.5		24.0		28.9	
Soil	-66	10.3		35.0		18.7	

the spectroradiometer's fiber optics collecting probe was substituted for the telescope module and extended out of the trailer. The rear of the trailer was covered with black cloth to minimize the stray reflected light reaching the dome. The end of the fiber optics probe was pointed upward and collected light from the total upward hemisphere according to a cosine function referenced to the zenith. Spectral irradiance was first read with the dome removed and then with the dome centered in place over the collector. The ratio of these two curves on a wavelength basis is the spectral transmission of the dome (Fig. 12). The displaced portion of the curves at wavelengths greater than .7μ results from the detector and grating used in the spectroradiometer for the longer wavelength intervals. The curves in the visible portion of the spectrum (.4 to .7μ) are about 2% lower than the average value of transmission of 92.5% supplied with them by their fabricator, and this may be due to the fact that they were dusty when the tests were conducted. New, revised transmission curves will be obtained for all four domes used in the photosynthesis experiments in the near future. The measurements obtained reinforce the concept that percent cover can be measured spectrally.

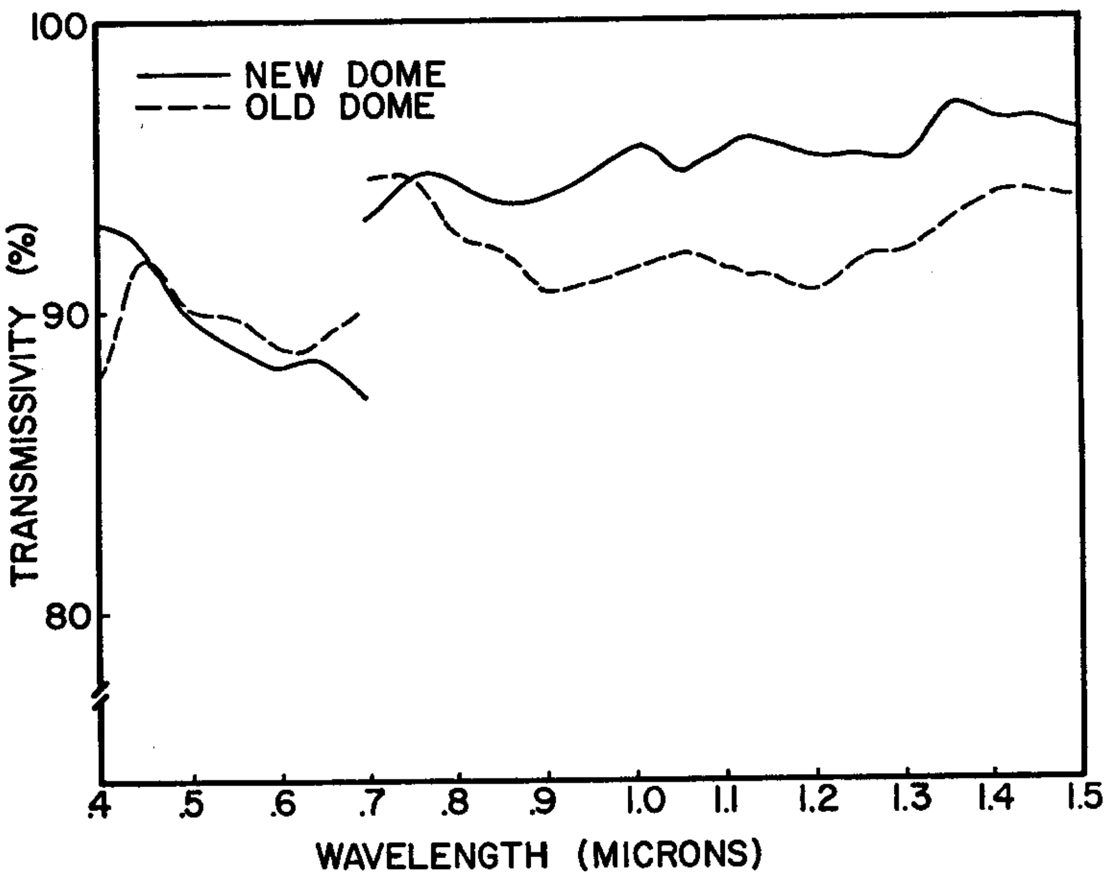


Fig. 12. Transmission curves of a photosynthesis gas collection dome.

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