DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

REMOTE DETECTION OF CHLOROPHYLL FLUORESCENCE OF SAGEBRUSH

GOLD RUN DISTRICT, HUMBOLT COUNTY, NEVADA

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ABSTRACT

Recent advances in the understanding of the role of chlorophyll fluorescence in the detection of stress conditions in plants has led to the desire to apply this tool to mineral exploration. The Fraunhofer line discriminator (FLD) has been used to detect differences in chlorophyll fluorescence indicating plant stress in citrus. An experiment was conducted to determine the possibility of detecting chlorophyll fluorescence differences which might result from anomalous concentrations of gold in sagebrush. The plants were apparently dormant and the results are inconclusive.

INTRODUCTION

In the human timescale, near-surface geochemistry is, except for the intentional or accidental alteration by man, essentially constant. If the land surface of the Earth were bare rock and sediment, the mapping of mineral resources with airborne and satellite sensors would be relatively simple; it is not. Most of the land surface is covered with vegetation, even those areas considered to be barren. Grasses, shrubs, and trees obscure the rock, sediment, and soil. The complete and unique spectral signature of the mineralogy cannot be remotely detected through the cover of these plants. But, these living, dynamic systems can provide indirect information on what lies beneath them. Plants are directly affected by the chemistry of the soil in which their roots are anchored. To some extent it controls the families and species of plants that will survive in an area. Changes in the soil chemistry, introduced by geologic prosesses or man, or encountered as a plant's root system grows, may affect the health of established plants. As living entities, plants adjust, as much as possible,to changing environmental conditions. These adjustments involve internal processes of the plants, foremost of which is photosynthesis.

Lichtenthaler and Rinderle (1988) report the acquisition of basic information on the functioning of photosynthesis in relation to plant stress from their study of the light-induced in vivo chlorophyll fluorescence of green plant tissue. The major share of absorbed light, under optimum conditions, is used for photosynthetic quantum conversion. Stress conditions may reduce the rate of photosynthesis without affecting the absorption process. This results in an increased release of energy through heat emission and chlorophyll fluorescence. Chlorophyll fluorescence emission has maxima near 690 nm and 740 nm (figure 1). Comparison between fully active and stressed plants can be made in direct sunlight using a Fraunhofer line discriminator (FLD). In a controlled experiment conducted at the University of Arizona Citrus Experiment Farm in Tempe, Arizona in 1980, thirteen trees were selected for drought-stress study. The results, reported by McFarlane et al (1980), clearly show the direct relationship between stress, indicated by higher stomatal resistance, and fluorescence at 656.3 nm. Although this wavelength is far down on the shoulder of the 690 nm emission peak and has been considered by some to be of too low an intensity to provide useful information, recent studies (Carter et al, in review) show that the FLD is also sensitive to changes in chlorophyll fluorescence produced by induction kinetics methods. Fluorescence induction kinetics is a technique whereby plants are dark-adapted and then exposed to blue light. The rapid change in red-light emission from an initial high intensity, through a minimum, to a steady state of a lower intensity than the initial maximum is commonly called the Kautsky affect and has been applied extensively for the past 25 years in photosynthesis research to describe and understand photosynthetic light reactions (Lichtenthaler and Rinderle, 1988). The success of the FLD instrument used in the chlorophyll fluorescence experiments to date supports the belief that other possible applications for the use of chlorophyll fluorescence as an indicator of stress should be explored.

An opportunity has arisen to determine the feasibility of using chlorophyll fluorescence and the FLD to detect stress which may be related to anomalous concentrations of gold in sagebrush. Erdman et al (1988) have done chemical analysis of big sagebrush (*Artemisia tridentata*) in Nevada and found many plants to contain anomalous levels of gold. There has also been a significant effort by the Branch of Geophysics to collect data in the area using other geophysical techniques.

METHOD

The FLD is a remote sensing instrument that uses a technique called the Fraunhofer line-depth method to detect luminescence emissions from natural and man-made materials stimulated by solar radiation. The Fraunhofer line-depth method requires four measurements to be made for each Fraunhofer line, with all measurements centered at the wavelength of the line minimum. The solar spectrum is measured from a diffuse, reflective, non-luminescent surface so as to include both direct sunlight and diffuse skylight. Measurements with a bandwidth of approximately 10 angstroms are designated, in the formulas shown below, *a* for solar continuum and *d* for target continuum. Measurements with a bandwidth of approximately 0.7 angstroms are labeled *b* for solar line-center and *c* for target line-center. If the target material is non-luminescent, then the intensities *c* and *d* will be equal to the intensities *b* and *a* times the reflectivity of the material and the ratio *c/d* will equal the ratio *b/a*. The luminescence emission bandwidths of materials investigated to date exceed the 10 angstrom continuum measurement bandwidth. Where the emission wavelength(s) correspond to a Fraunhofer line, then that radiation will increase both the *c* and *d* intensities and the *c/d* ratio will be greater than the *b/a* ratio indicating the presence of a luminescent material. Algebraically, the problem can be stated in the following manner: If R = reflectivity and L = luminescence, then

$$c = Rb + La \tag{1}$$

and

$$d = Ra + La. \tag{2}$$

Subtracting equation 1 from equation 2 gives

$$R = (d-c) / (a-b), \tag{3}$$

the reflectivity of the material, expressed as a percentage, derived from the measured intensities. Rewriting equation 2 yields

$$L = (d/a) - R \tag{4}$$

and substituting for R from equation 3 gives

$$L = (d/a) - [\ (d-c) / (a-b)\ ], \tag{5}$$

the luminscence coefficient, a number less than one, derived from the measured intensities. For a more complete discussion, see Plascyk (1975). In this paper the term "fluorescence" is used where the source of the non-reflectance emission is known or assumed to be from the chlorophyll fluorescence of the sagebrush. The term "luminescence" is used where the exact nature of the emissions is unknown or as to include all of the non-reflectance emission measurements. For convenience, the relative luminescence used in this text represents the luminescence coefficient times 10,000.

For this experiment the FLD optical head was attached to the end of the horizontal beam of a stiff-armed crane mounted in the back of a pickup. No imaging of bushes was attempted, rather the FLD was operated in the single-point radiometer mode. Data were recorded with a digital printer connected directly to the output of the electronic console. A reflectance-standard ceramic chip was physically placed on a bush to confirm correct alignment of the optical head, and reflectance and luminescence measurements were taken for the chip and the bush. Additional measurements were made at each bush of ground in shadow and in full sunlight. These measurements were made to aid in determining instrument drift and data integrity.

SITE SELECTION

In selecting a site for luminescence data collection, several considerations had to be made. Access to the site by vehicle (four-wheel-drive pickup) was imperative; the equipment is too heavy for back-packing. Aircraft mounting for such a preliminary test would have been prohibitively expensive and the resolution of 45 m for the airborne imaging system used in the past is too coarse. The location had to include two populations of plants that differed in their gold content but not in their physical appearance. Corroborative evidence of an anomaly from some other remote-sensing technique would be a positive deciding factor.

A portion of traverse C, from a study site of Erdman et al (1988) near Hot Springs Ranch in the Gold Run District, Humbolt County, Nevada seemed to meet all of the above requirements. Figure 2 shows the location of traverse 1 where luminescence measurements were made. Traverse C extends from the adit west of the range front fault to the location of traverse 1 site 15 east of the irrigation ditch. Traverse 1 sites 1-12 overlap with traverse C sites C07-C10 and sites 13-15 are in close proximity to C11. The sagebrush chemistry from sites C07-C10 indicated no measureable gold, while the C11 site contained measureable traces. Traverse C sites C07-C10 are separated from C11 by the irrigation ditch. Electrical methods employed by Don Hoover, U.S.G.S. Branch of Geophysics, Denver, indicate that the area of C07-C10 is "dead" and that of C11 is anomalous (personal communication).

DATA INTERPRETATION

October 29, 1988 began, in Winnemucca, Nevada, with a mildly, but uniformly, overcast sky which cleared during the day to complete blue. These sky conditions are just right for an instrument that is used to measure solar-stimulated luminescence. There was also no wind which, if it is too strong, can affect the photosynthetic process in active plants. Unfortunately we had apparently arrived too late in the year, overnight sub-freezing temperatures were already occuring. Although sagebrush has an evergreen habit in the cold desert, seasonal photosynthetic activity is largerly limited to spring and early summer and the final phenological stage occurs from late August to mid-September (Caldwell, 1985). In a telephone call to Dr. Caldwell, an ecophysiologist at Utah State University, Logan, he confirmed that under the observed conditions of the plants, low air temperatures, and very low soil moisture the plants were most likely inactive or dormant. Without the photosynthetic process in an active state there is no difference between the fluorescence of stressed and non-stressed plants.

To be sure that this conclusion was correct, and also that the fluorescence measured over each individual bush was not being influenced by external factors or faulty instrument operation, several different combinations of correlations of the data were made. First, bush fluorescence was compared to bush reflectance. The correlation coefficient (r) was +0.01, essentially no correlation what-so-ever. This is a positive statement because the FLD luminescence and reflectance values are derived from the same four spectral measurements, and a high correlation would indicate faulty operation of the instrument. Bush fluorescence compared to ground luminescence produced r = +0.24. Bush fluorescence to ground reflectance was r = +0.12, and bush reflectance to ground reflectance was -0.43. None of these correlations connote any significance other than that the bush fluorescence is not influenced by ground luminescence. Scatter plots of these data are shown in figures 3A-3D respectively. To determine if the anomaly identified from plant chemistry and electrical methods might be revealed in any of the luminescence or reflectance data, these data for both bush and ground were plotted versus site location. The correlations for bush fluorescence (r = -0.01), bush reflectance (r = -0.26), ground luminescence (r = +0.03), and ground reflectance (r = +0.08) also are not of a magnitude to be considered significant. The plots of these data are in figures 4A-4D respectively.

CONCLUSIONS

An area to test the feasibility of detecting stress in sagebrush containing anomalous levels of gold using chlorophyll fluorescence has been found to meet the necessary criteria for collecting data, and the cost of such an endeavor has been found to be low. No conclusions can be drawn from luminescence data taken when plants are dormant because the active process of energy transport within the plant, which might be affected by anomalous concentrations of gold, is not in operation. A return trip to this area when the plants are photosynthetically active is necessary to answer the question with any certainty.

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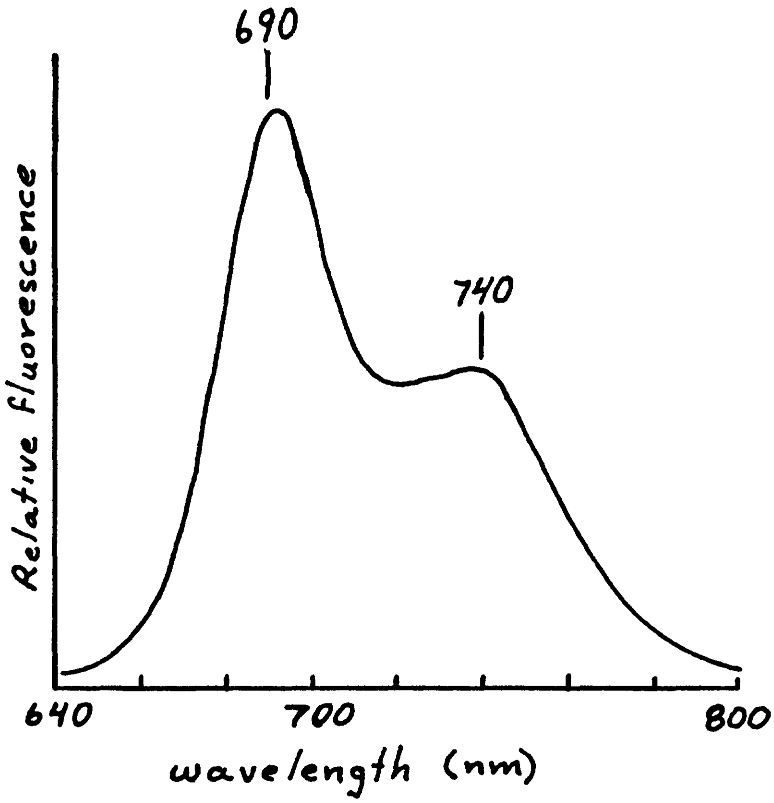

Figure 1. Fluorescence emission spectrum of a green Norway maple leaf (Acer platanoides). Adapted from Lichtenthaler et al (1986).

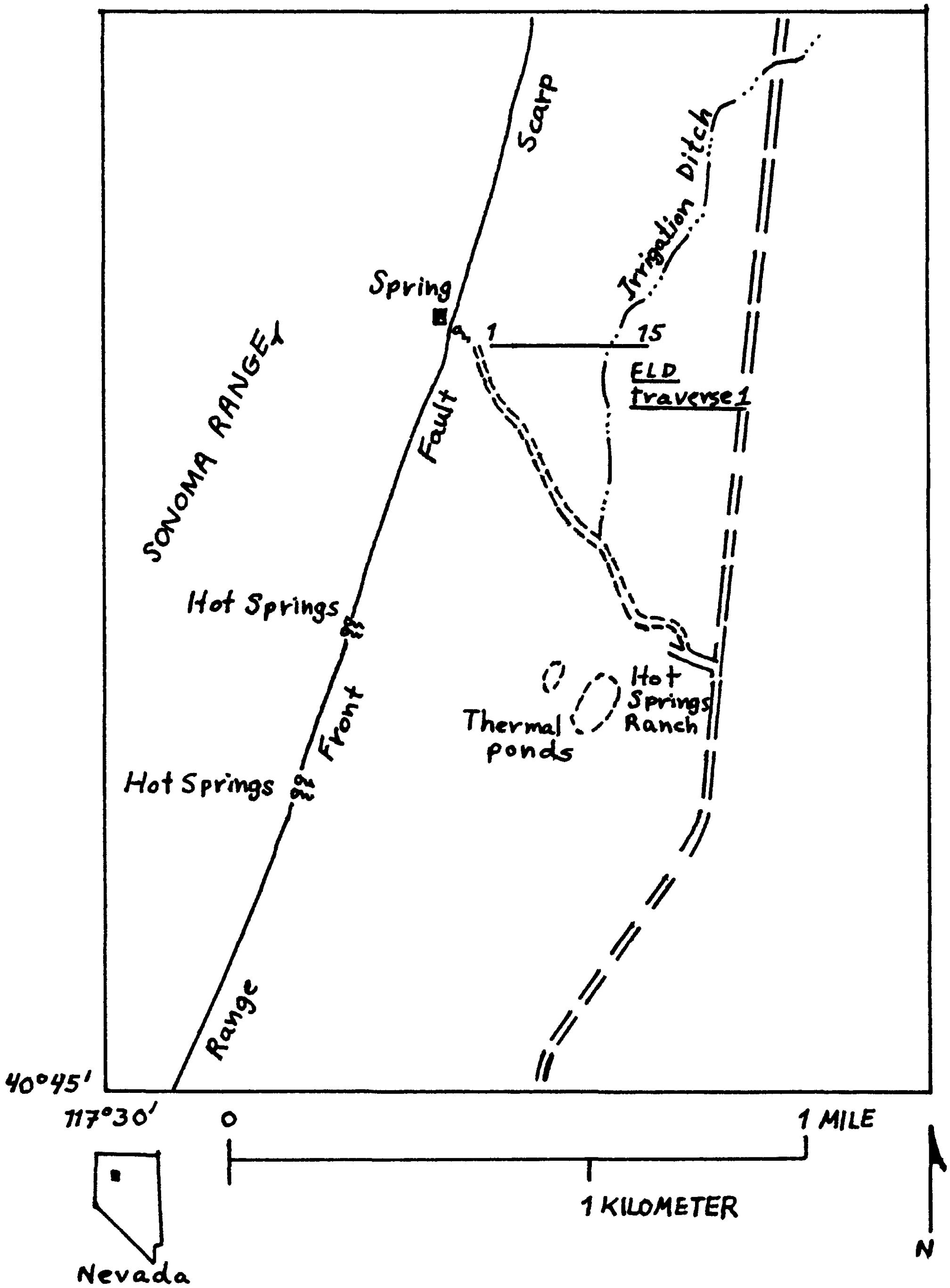

Figure 2. Base map showing FLD luminescence traverse. Adapted from Erdman et al (1988). The FLD luminescence data were collected from sagebrush and adjacent ground areas along a path corresponding to traverse C (figure 4, Erdman et al, 1988). The reference map is Goldrun Creek Quadrangle, Nevada-Humbolt Co. 7.5 minute series.

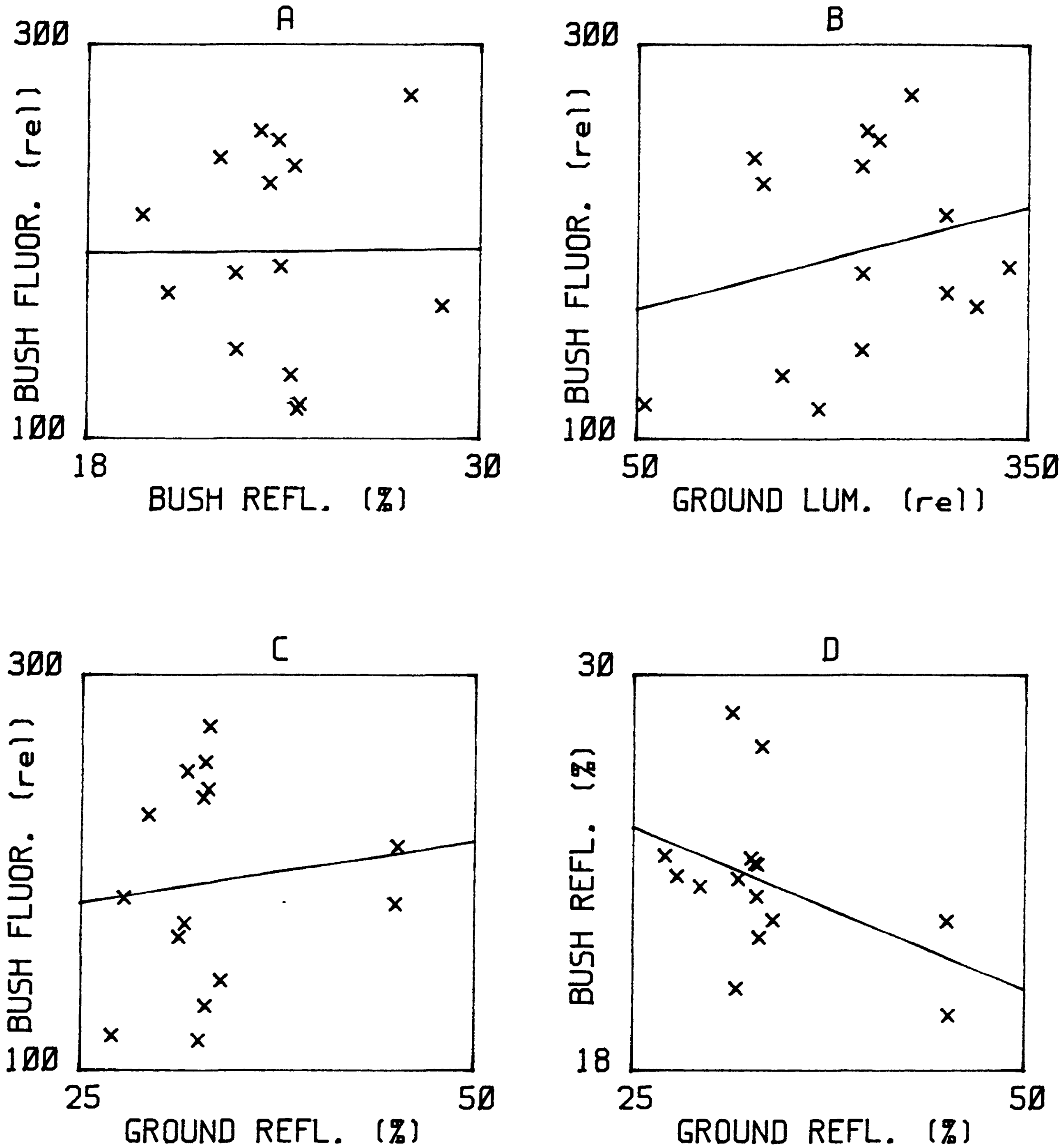

Figure 3. Correlation plots of sagebrush and ground measurements. The relative luminescence shown in these plots is the luminescence coefficient times 10,000. There are no strong correlations for these data. However, for the purpose of completeness, the correlation coefficients are respectively: r(A) = +0.01, r(B) = +0.24, r(C) = +0.12, and r(D) = −0.43.

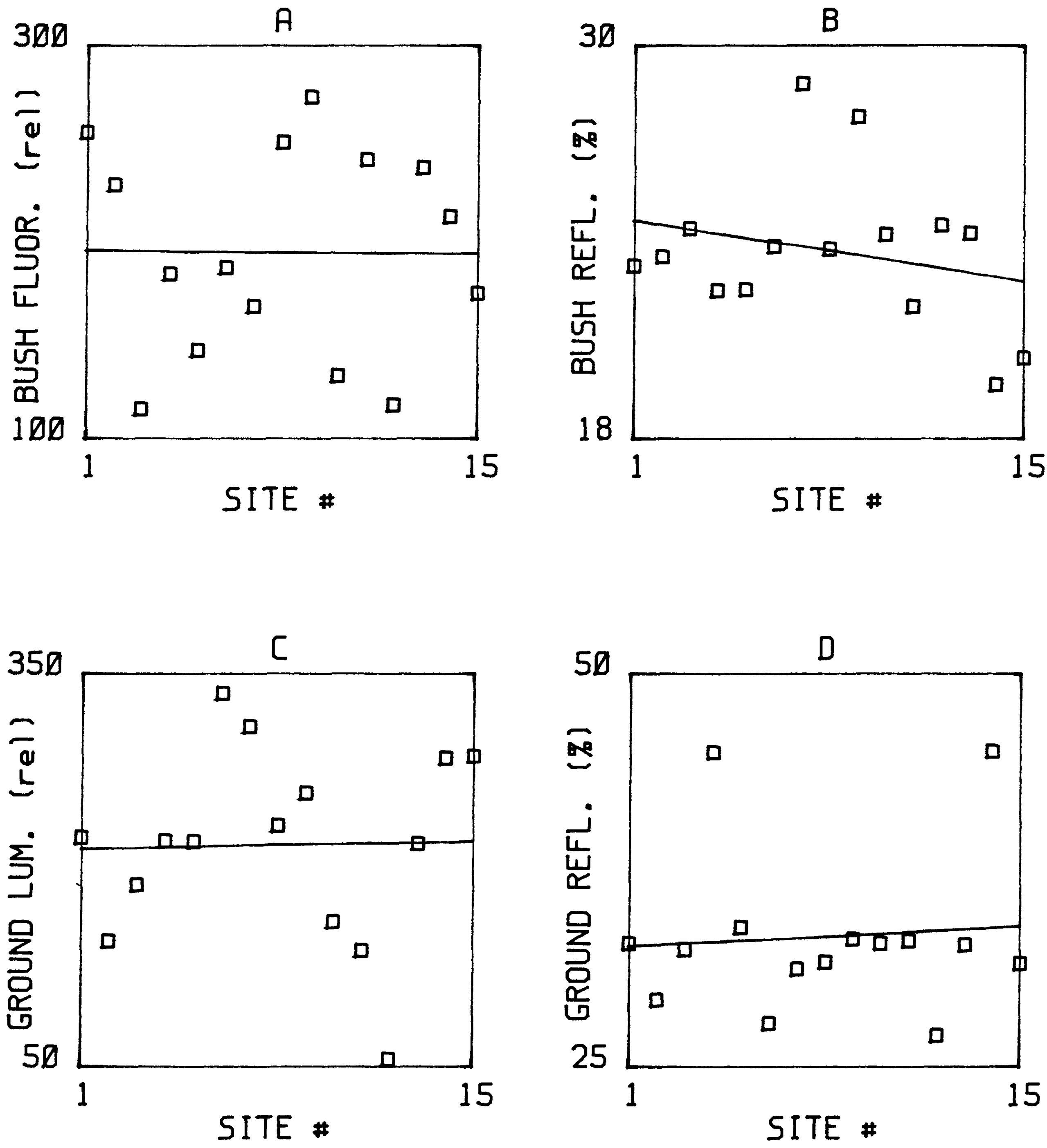

Figure 4. Sagebrush and ground measurements along traverse 1. The site #'s refer to figure 2, and 1 through 15 run west to east down slope. The relative luminescence shown in plots A and C is the luminescence coefficient times 10,000. The correlation coefficients are respectively: r(A) = -0.01, r(B) = -0.26, r(C) = +0.03, and r(D) = +0.08.