Order Number 1332531

Litter cover effect on soil spectral response

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The University of Arizona, 1987

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LITTER COVER EFFECT ON SOIL SPECTRAL RESPONSE

by

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A Thesis Submitted to the Faculty of the

THE DEPARTMENT OF SOIL AND WATER SCIENCE

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. Allan D. Matthias who served as thesis director for this research. The guidance and understanding provided by Dr. Matthias throughout my M.S. program was excellent, and I thank him for this. The author is also grateful to Drs. Donald F. Post and Alfredo R. Huete for their advice and for serving as member of his M.S. committee.

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ABSTRACT

In order to assess the influence of litter cover on soil background spectral response, trays of dry Lehmann Lovegrass (Eragrostis lehmanniana) were used at three different densities (635, 1015, 2815 Kg/ha) over three different soil backgrounds (Whitehouse sandy clay loam, Superstition sand, and Cloversprings loam). After analysis, spectral measurements made with a Barnes Multi-Modular Radiometer revealed that, soil-litter mixtures exhibit a oil like spectral behavior in the (0.45-2.30 m) waveband range. Mulched soils could not be discriminated from bare soils solely on the basis of the spectral response. However, mulched and bare soil spectral responses differed in amplitude depending on the difference in brightness between the bare soil and the litter cover. In addition, the results showed that while an increase of litter cover density on the soil surface decreased RVI, NDVI and PVI predicted greenness, it increased the GVI based greenness for all soils except the Superstition sand where the GVI showed a reversed trend. The PVI increased at low and intermediate litter densities and decreased at higher ones for the Superstition sand.

CHAPTER 1

INTRODUCTION

The need to discriminate vegetation from soil background is partly responsible for the development of spectral vegetation indices. These indices are obtained by ratioing, differencing or otherwise transforming and combining judiciously chosen spectral bands to enhance plant canopy spectral characteristics while minimizing soil background noise. However, the variability in time and space of soil background spectral response limits the reliability of these indices. Jackson, Slater and Pinter (1983) found them to be soil moisture-sensitive. Elvidge and Lyon (1984) showed their dependence upon soil brightness; they reported that darker soil backgrounds resulted in lower greenness measures for the same amount of green biomass for ratio indices. Huete et al. (1984) showed that spectral variation among soil backgrounds can seriously hamper vegetation discrimination.

It appears that understanding soil spectral behavior is a prerequisite to a better analysis and interpretation of remotely sensed data since the removal of soil-induced noise is a sine qua non condition to achieving relative accuracy in vegetation assessment.

Many factors affect soil spectral response; soil spectral properties result from the cumulative effect of heterogenous combination of mineral, organic and fluid materials constituting the soil medium but also from all reflecting materials within the sensor field of view. Thus, soil reflectance as perceived through a sensor is a composite value that accounts for all relative spectral contributions from all reflecting bodies within the scene. Several, studies have related certain soil properties to their spectral response. Particle size, mineralogy, structure, color, moisture and organic matter content have been reported to greatly affect soil spectral behavior (Westin, 1973; Obukov and Orlov, 1964; Da Costa, 1979).

The spectral properties of a mineral vary with particle size, the water film and organic and inorganic coatings around each mineral grain (Hovis, 1966). The high reflectance of soils with gypsic mineralogy is attributable to the inherent properties of this mineral. Kaolinite, gibbsite and muscovite will affect soil reflectance due to the hydroxyl effects. Quartz and feldspars are spectrally featureless (Da Costa, 1979). Montmorillonitic soils with high water content and organic matter exhibit very low reflectance. Ferrous and ferric oxides are highly responsive in the red region of the spectrum and exhibit an absorption zone at 0.7 and 0.9 micrometers. The region ranging from 0.50 to 0.64 micrometers is very sensitive to soil iron content (Obukov and Orlov, 1964). Silicate minerals owe their spectral properties to the fundamental silica-oxygen vibration patterns which are easily detected in the 8-14 micrometer bandwidth.

Laboratory particle size measurements (spectrophotometry) have shown that spectral properties of minerals are inversely proportional to particle size diameter; the bigger the diameter the lower the reflectance. However, fine-textured soils generally have the properties to form aggregates coarser than sand and they therefore reflect less than sand in field conditions (Myers and Allen, 1968). This may be ascribed to the shadowing effect that results from the crusting of soil particles into aggregates that tend to have irregularly shaped interaggregate spaces in which the incoming radiant flux is trapped. Structureless soils reflect more than soils with well defined structures (Tolchel'nikov, 1959) yet, the influence of structure seems to be dominant over that of texture (Orlov, 1966). On the other hand, medium fine-textured soils show a decreasing reflectance trend with decreasing particle size possibly because of the increased moisture and organic matter content associated with high clay percentages (Da Costa, 1979). In general, silty soils (> 90% silt) tend to have the highest reflectance at all wavelengths whereas sand has lower reflectance than clay in the 0.4 - 2.5 micrometer region (Johannsen and Baumgardner, 1968).

Soil color is mostly affected by mineralogy, moisture and organic matter content (Da Costa, 1979). Only the visible fraction of the electromagnetic energy spectrum is affected by soil color. Textural and mineralogical differences are better revealed by measurements in the near and the middle infrared. An increase in soil moisture content decreases soil reflectance throughout the 0.4 to 2.5 micrometer spectral region. Weak and strong water absorption bands are observed at 1.4 and 1.9 micrometers, respectively. Yet, actual soil moisture content has been found to be most highly correlated with soil reflectance in the 2.08 to 2.32 micrometer region (Johannsen and Baumgardner, 1968). Overall soil water content has a "darkening" effect on soil reflectance (Planet, 1970; Angstrom, 1925; Condit, 1970).

Organic matter is one of the most important parameters affecting soil surface spectral response. Generally, soil reflectance decreases throughout the reflective spectrum with increasing organic matter content. However, soils with less decomposed organic matter have higher reflectance in the near infrared region due to enhanced multiple reflection effects from remnant cell structures (Da Costa, 1979). Nondecomposed organic matter, often referred to as litter, is found on the soil surface in variable quantity following the growing season. Litter production, density, decomposition and distribution over time and space is not uniform, therefore, litter cover adds to the soil background-induced limitations in the use of vegetation indices for greenness assessment.

This study investigates the effect of litter on soil surface spectral properties. The main objectives are: (a) to study soil and litter composite spectral response in the visible, the near and the middle-infrared spectral regions; (b) to understand litter-induced limitations on the ability of vegetation indices to accurately estimate green vegetation parameters.

CHAPTER 2

EXPERIMENTAL PROCEDURE

Materials

Three different densities of senesced yellow Lehmann's love grass, Eragrostis lehmanniana (635, 1015, and 2815 Kg/ha) were collected and attached to nets of fine brown twines to simulate ground litter. For ease of operation, but also in order to prevent any change in density or distribution, litter covers were sandwiched between two wooden frames. A circle of 0.5 m^2, removed from the middle of the frames allowed a mixture of soil and litter to be simultaneousely viewed by the sensor. Litter trays thus prepared were used to measure soil-litter spectral response over different soil backgrounds under dry, moist and wet conditions. Three boxes containing different soils provided the needed soil background variation. The three soils used for the experiment are samples of the Whitehouse, Cloversprings and Superstition series. They were collected in 1.2 x 1.2 x 0.4 meters boxes. The study was conducted on September 12, 1985 at the University of Arizona Campus Agrultural Center in Tucson, at morning sun elevation angles. The elevation sun angle bracket varied from 60.10^o to 61.60^o. The local longitude and latitude are 110.95^o and 32.29^o, respectively.

Classification of the Soil Backgrounds

Two of the three soils, Cloversprings loam and Superstition sand were surface soils of the (A) horizon whereas the Whitehouse sandy clay loam soil was from a subsurface (Bt) horizon. The latter is a common Southern Arizona rangeland soil, moderately fine-textured, high in extractable iron (dark-red-color), and very low in organic matter. The Cloversprings is a medium-textured, very dark-colored organic rich soil typical of midwestern agricultural soils. The bright yellowish-brown Superstition sand is representative of alluvial and eolian soils; taxonomically it is a sand. All three soils surfaces were relatively smooth, with aggregates sizes ranging from less than 1 mm up to about 15 mm. Table 1 gives specifc physical characteristics of the three soil backgrounds.

Measurements

Reflectance readings were taken with a Barnes Multi-Modular Radiometer (MMR). This 15^{0} field of view instrument is equipped with seven spectral bands (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90, 1.15-1.30, 1.55-1.75, and 2.08-2.30 micrometers). The radiometer was mounted on a yoke and held at constant height (1.6 m) above the target; this allowed a viewed surface of about 0.5 m^2. All readings were taken under very low haze and cloud-free skies. For reading standardization, a 1.2 m x 1.2 m $BaSO_4$ plate was used to simulate a lambertian surface. Plate readings were taken before and after target reading.

Measurements were made using one litter tray laid over each soil background one at a time. All readings were taken first under wet and then under dry condition for a given soil type. A third set of measurements was taken over soils in the drying process. Soils were wetted with a fine garden sprayer to avoid any disturbance of their surface. During measurements, litter trays were kept dry and positioned above the soil whose reflectance was to be determined.

Table 1. Physical characteristics of soil backgrounds

Soil Series	Textural Class	Organic Matter(%)	Iron (EXT.%)	*$CaCO_3$ (%)	Munsell color
Cloversprings.	Loam	5.7	1.8	0	10YR 2/1 wet 10YR 3/2 dry
Whitehouse (B)	Sandy clay loam	1.5	2.5	0	2.5YR 3/6 wet 2.5YR 3/6 dry
Superstition	Sand	0.2	0.2	3	10YR 5/4 wet 10YR 7/4 dry

* extractable

Wetting the litter trays could result in dew-like water droplets that may impact reflectance (Pinter et al., 1982). A dense yellow litter measurement was made by stacking all three litter trays. This provided a "pure" yellow signature used in this study. Reflectance reported in the present study were averages of 10 readings.

CHAPTER 3

SPECTRAL BEHAVIOR OF SOIL-LITTER MIXTURE

Soil background spectral variability can be attributed to many factors: soil type, soil moisture, surface roughness, shadow, litter or vegetation cover, etc. The present study focusses on the effect of litter on soil spectral response. Spectral reflectance responses of soil-litter mixtures were determined for each bandpass as ratios of target radiance to the plate radiance times the plate reflectance factor corrected for solar zenith angle. Results of these measurements are given in Figures 1, 2, and 3 as plots of percent reflectance vs wavelength for each soil, at each level of litter density, under wet and dry conditions.

Litter Effect

Litter soil composite signature exhibited a soil like reflectance pattern with a steady increase throughout the visible spectrum. In the near infrared region the curve reaches a maximum around 1.6 m before decreasing gradually in the middle infrared region. The maxima of the spectral curves are reached earlier (1.2 um) under wet substrates and low litter densities only for wet Whitehouse and wet Superstition. This is probably due to a much stronger water absorption effect in the middle infrared region due to the larger portion of bare wet soil "seen" by the sensor at low litter densities. The shape of the spectral curves remained the same for all soil backgrounds.

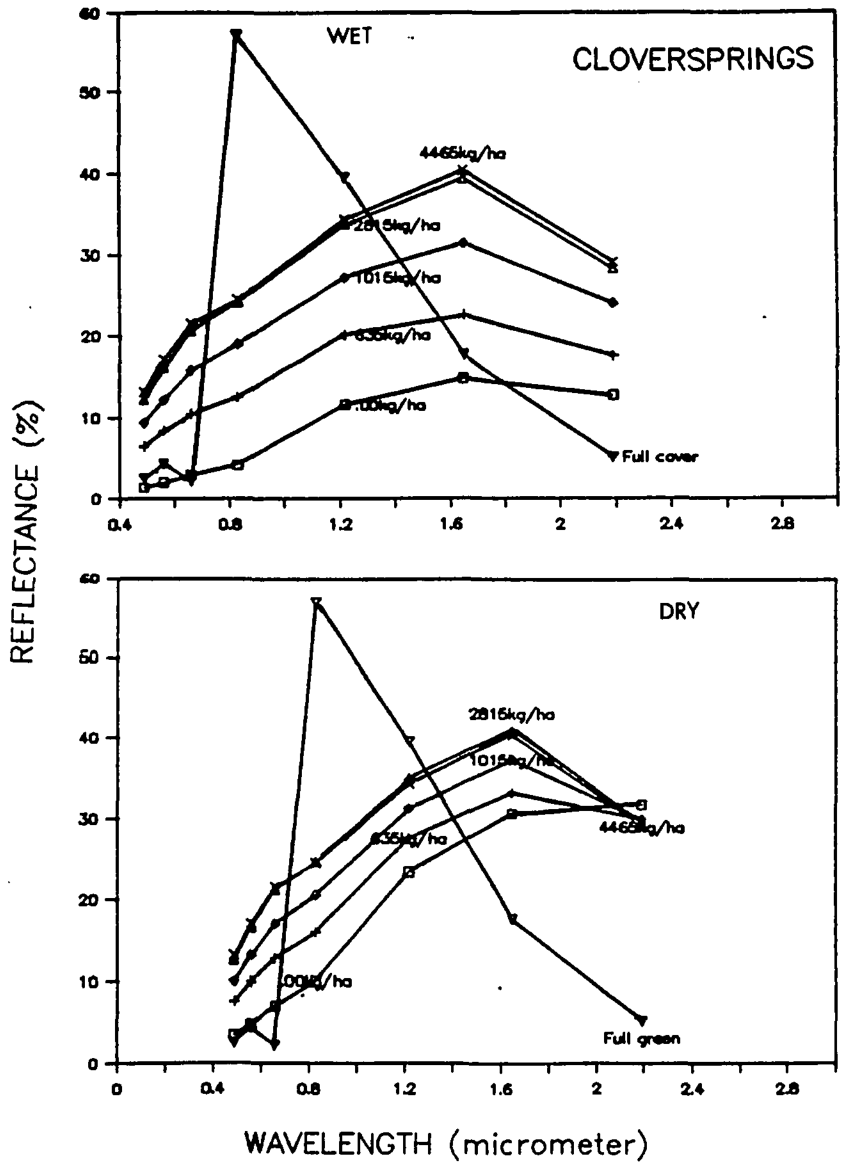


Fig. 1. Soil-litter composite reflectance for various litter cover densities contrasted with a green vegetation spectral response on a Cloversprings background dry and wet.

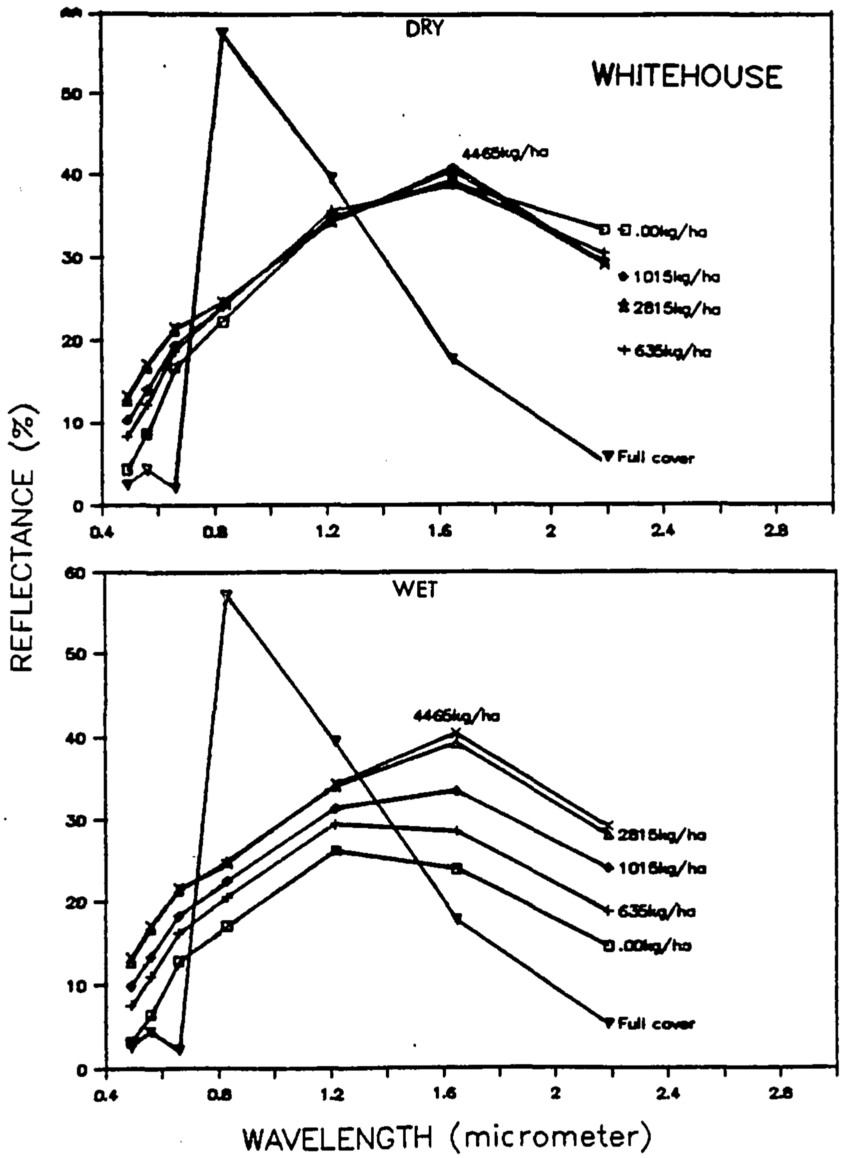


Fig. 2. Soil-litter composite reflectance for various litter cover densities contrasted with green vegetation spectral response on a Whitehouse background dry and wet.

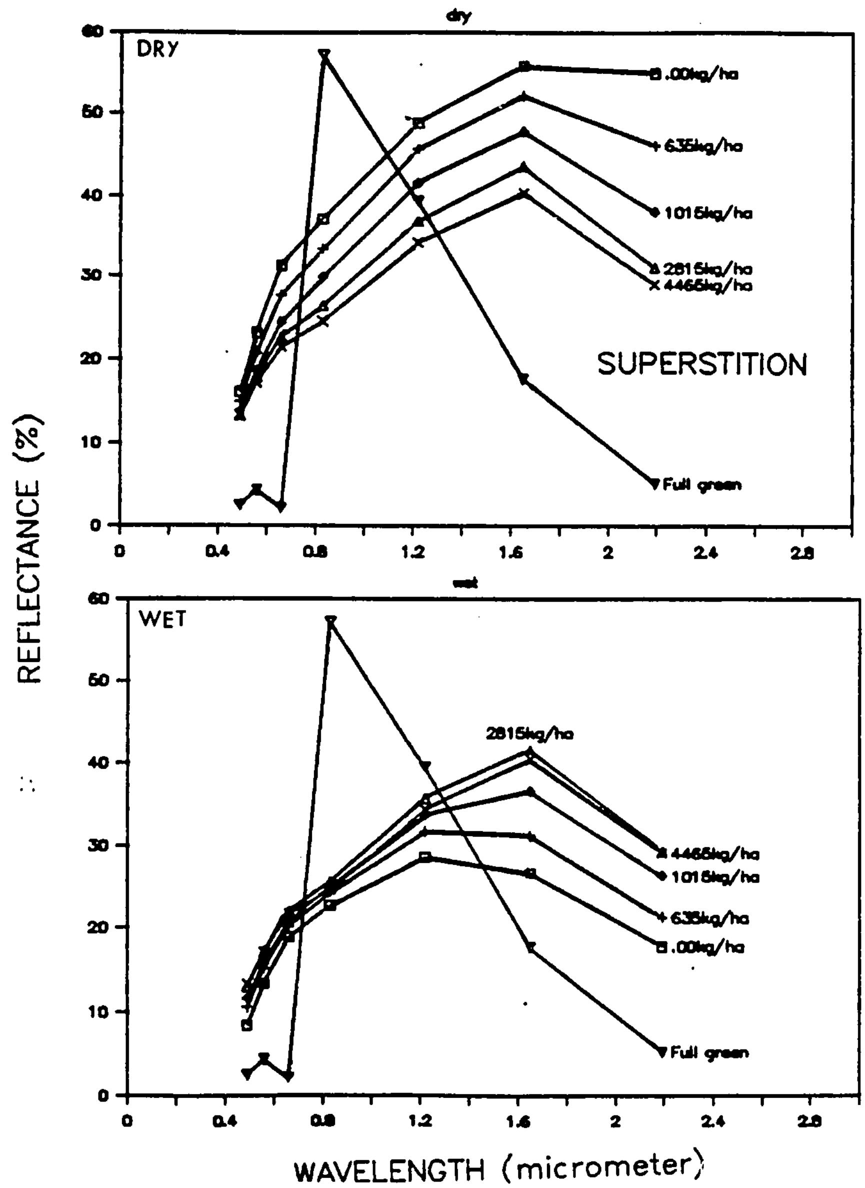


Fig. 3. Soil-litter composite reflectance for various litter cover densities contrasted with a green vegetation spectral response on a Superstition background dry and wet.

In the wavelengths used for this study, dry vegetal material could not be discriminated from bare soils solely on the basis of their respective spectral signature responses. In those spectral bandpasses, litter cover and bare soil can be easily confused (Figs. 1, 2, and 3).

Soil Background

The litter effect on soil spectral behavior seems to be governed by the difference in brightness between litter cover and the bare soil surface. If this difference is positive, litter cover enhances soil reflectance as depicted in Figure 1; litter lowers soil surface reflectance when litter brightness is lower than the underlying soil surface (Fig. 3). If the contrast between soil and litter is very small (Whitehouse), litter cover has little or no marked effect on the composite reflectance (Fig. 2). Table 2 presents contrast values between litter cover and soil as a difference in brightness between the two materials. Signs (+) or (-) are included to indicate the direction of the overall effect of litter cover on bare soil surface spectral response. The near infrared and the red reflectance did not, respectively, show the increase and the decrease that characterize green plant spectral signature in those regions of the electromagnetic energy spectrum (Fig. 4). The Brightness is used here is the sum of all spectral bands.

Moisture Effect

Soil moisture plays a significant role in determining soil spectral response by affecting soil color value (Horvath, 1981). In this

Table 2. Contrast (litter-soil) between litter and soil

Superstition		Whitehouse		Cloversprings	
dry	wet	dry	wet	dry	wet
-36.82	-18.56	-0.28	+26.32	+8.9	+28

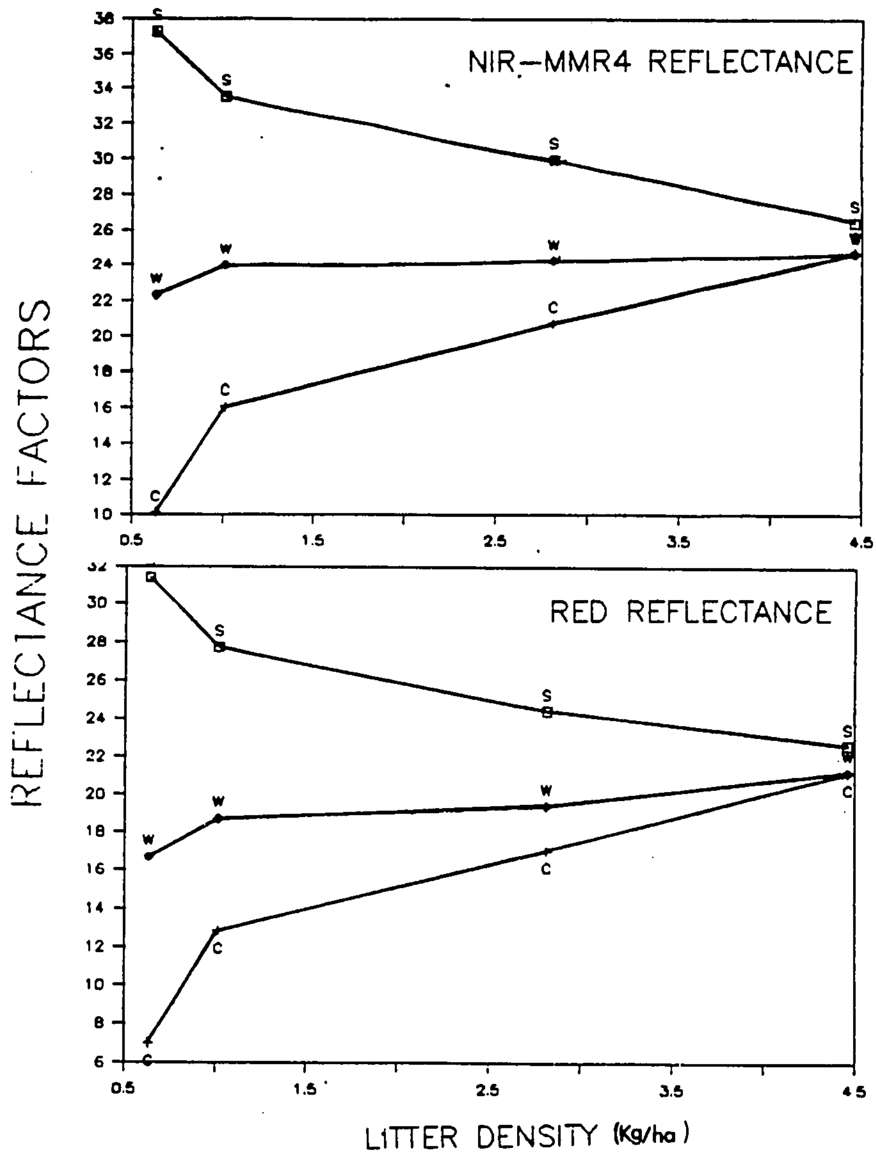


Fig. 4. Near (MMR-R) infrared and red (MMR-3) reflectance as a function of litter cover density.

study, the soil moisture effect was highly noticeable in its interaction with different soil backgrounds. On a Superstition sand background, for the same litter density, litter cover decreased soil reflectance under dry conditions while enhancing it under wet conditions. Wetting the soil reversed the contrast "sign" from negative to positive (Table 2). On the Whitehouse substrate, the contrast between dry soil and litter was very low, litter and bare soil spectral curves were superimposed on each other; moistening this soil resulted in a well defined contrast between litter cover and the Whitehouse background: on the wet substrate, spectral curves were better resolved from one another. On the Whitehouse background, moisture effect was most markedly noticeable in the NIR region where the converging trend of the dry soil spectral curves is replaced by a series of well-resolved lines on the wet background (Fig. 2).

Litter Density Effect

To further study soil-litter spectral interactions, we plotted measured soil-litter reflectance (R_m) against soil background reflectance (R_s) in each waveband for various levels of litter density and 3 different soil backgrounds (Figs. 5, 6, 7, and Appendix C). The results indicated that soil-litter composite reflectance was a linear function of soil background reflectance of the form

$$Y = aX + B \qquad (1)$$

which in spectral terms may be described by the following:

$$Dm / E_o = R_m = R_s \; T^2 + R_l \qquad (2)$$

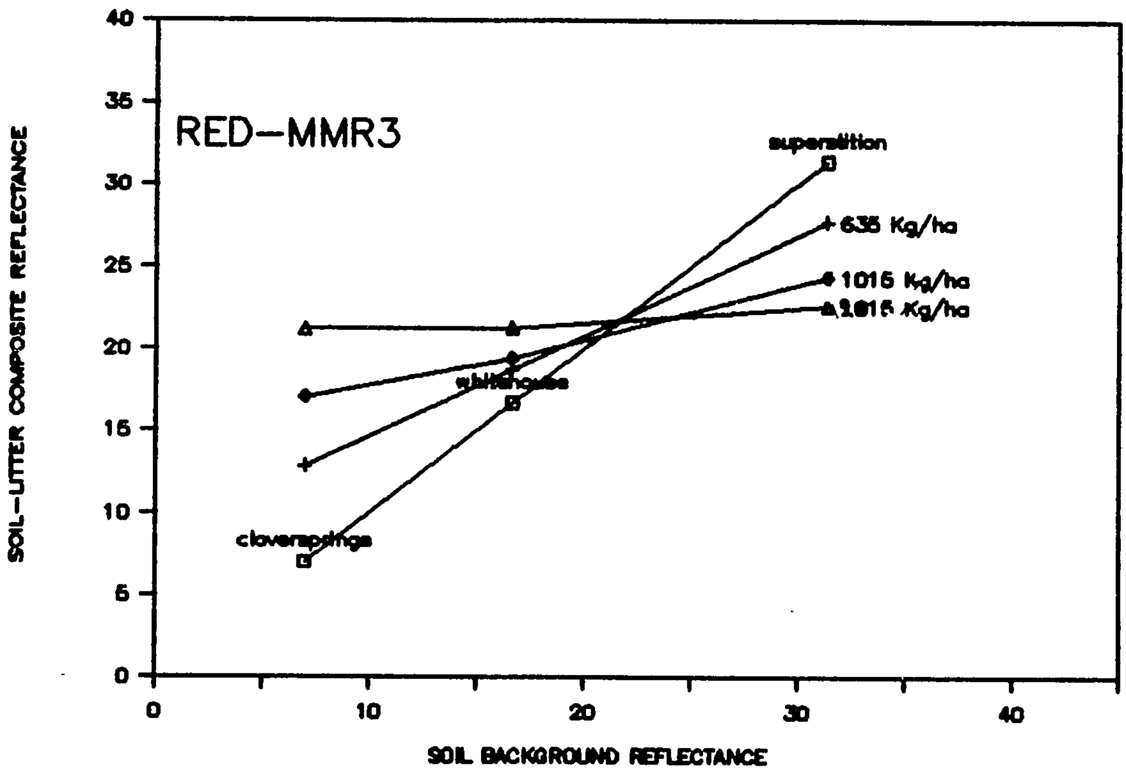


Fig. 5. Soil-litter RED-reflectance as a function of soil background reflectance for various level of litter cover density.

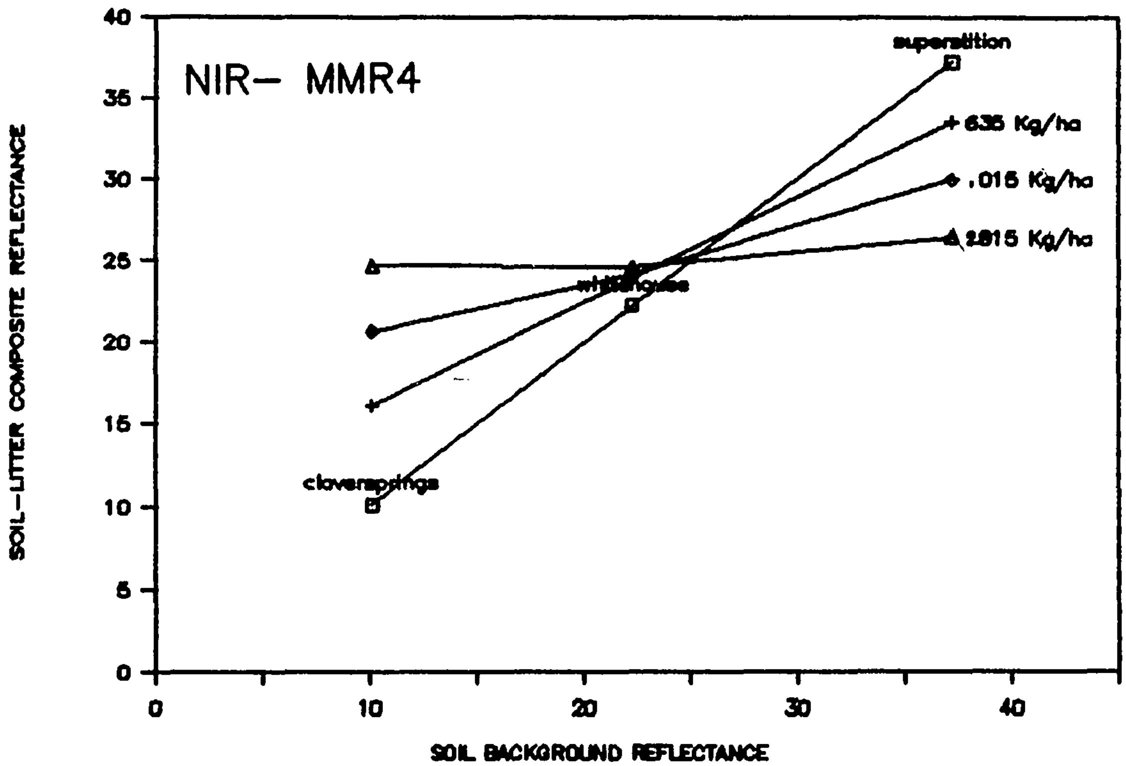


Fig. 6. Soil-litter NIR (MMR-4) reflectance as a function of soil background reflectance at various litter densities.

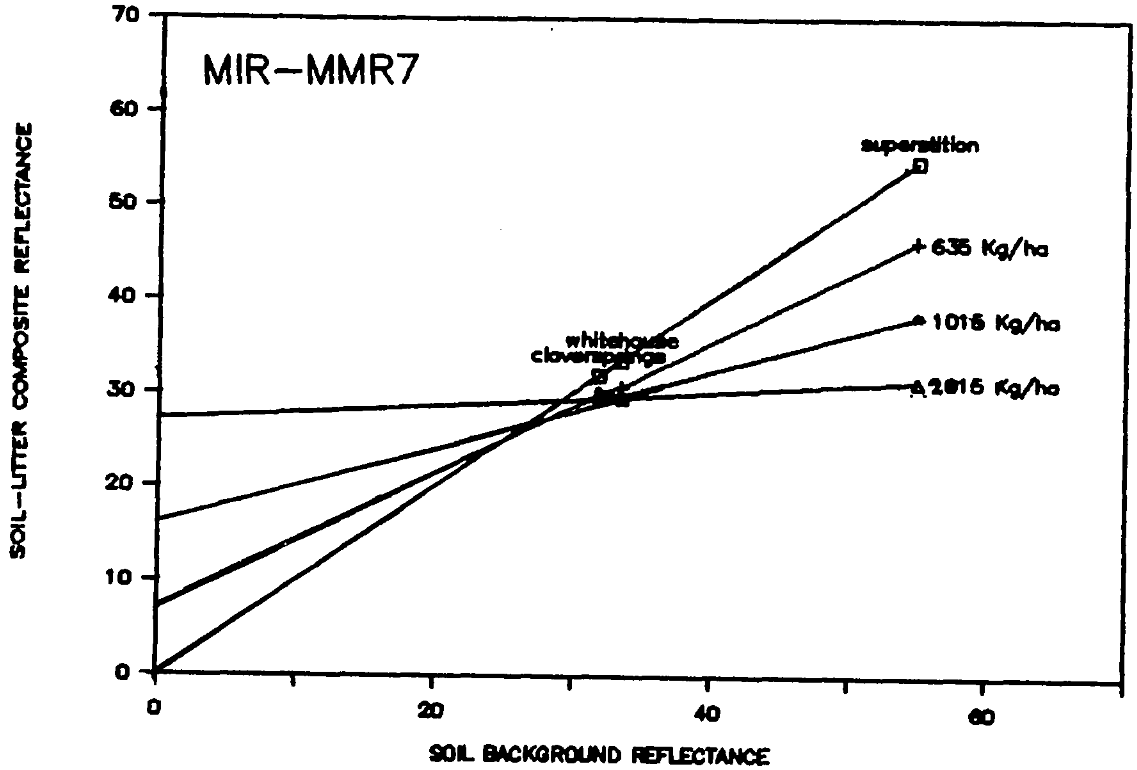


Fig. 7. Soil-litter MIR-(MMR-7) reflectance as a function of soil background reflectance at various litter densities.

where D_m = measured response

R_m = measured soil-litter reflectance

R_s = bare soil reflectance

T^2 = two-way litter penetration

R_l = litter component reflectance without a " zero" soil

E_o = global irradiance

Equation (2) is analogous to Huete's (1987) radiative flux transfer in a soil-plant system model. It expresses the measured composite reflectance (R_m) as a ratio of the measured spectral response (D_m) to the total irradiance (E_o).

Equation (2): $D_m/E_o = R_m = R_S = T^2 + R_l$ describes the composite reflectance (R_m) as a linear combination of two independent spectral contributions from the soil (R_s) and the litter cover (R_l). The soil component is affected by a two-way penetration factor (T^2) which is the radiant flux, interacting with the soil background, and reflected back through the litter cover to the sensor (Fig. 8).

The two-way penetration factor (T^2), like all the terms of the spectral expression (2) is wavelength dependent but like R, (T^2) is a bounded function that varies between 0 and 1 (Fig. 6): [$0 < T^2 < 1$]. Physically, (T^2) represents the slope of the spectral curves as plotted in Figures 5 and 7. A penetration factor of one ($T^2 = 1$) corresponds to a bare soil surface where no obstacle prevent the radiant flux from reaching the soil background. On the other hand, a penetration factor of zero ($T^2 = 0$) would represents a dense litter cover that shields the

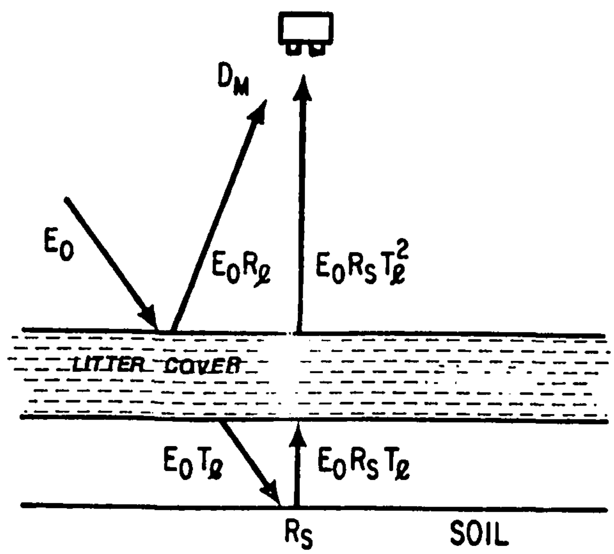


Fig. 8. Radiative transfer model involving flux interaction with a litter cover-soil background system (E_0 = global irradiance; T_l = litter penetration factor; R_l and R_s are litter and soil reflectances; D_m = measured response.) (adapted from Huete (1987)).

soil background against the solar radiant flux. At this point no measurable quantity of the solar energy interacts with the soil background.

Geometrically, the two-way penetration factor (T^2) may be expressed as the ratio of the difference in composite reflectance between two, light and dark, soil backgrounds to the difference in reflectance between the same bright and the darkest bare soils (Fig. 9). T^2 increases throughout the visible and the NIR and decreases in the middle infrared MIR regions (Fig 10).

$$T^2 = R_m / R_s \tag{3}$$

$R_m = L_{brt} - L_{drk}$

$R_s = S_{brt} - S_{drk}$

L_{brt} = Litter + bright soil reflectance

$L_d{}^{kr}$ = litter + dark soil reflectance

S_{brt} = bright soil reflectance

S_{drt} = dark soil reflectance

In the plots of soil-litter reflectance vs soil reflectance (Figs. 5, 6, 7 and Appendix C), the intercepts of the lines are in fact litter spectral response without soil background influence (a zero reflecting background). Each line represents a constant litter density (biomass). A bare soil line assumes a 45^o direction with regard to the horizontal in all wavebands. As litter accumulates on the soil surface, the line undergoes a gradual clockwise rotation from 45^o to [(45^o-$\tan^{-1}T^2$)] about the point of equal reflectance (soil reflectance equals litter reflectance). When T^2 = 0, the line has rotated 45^o; at

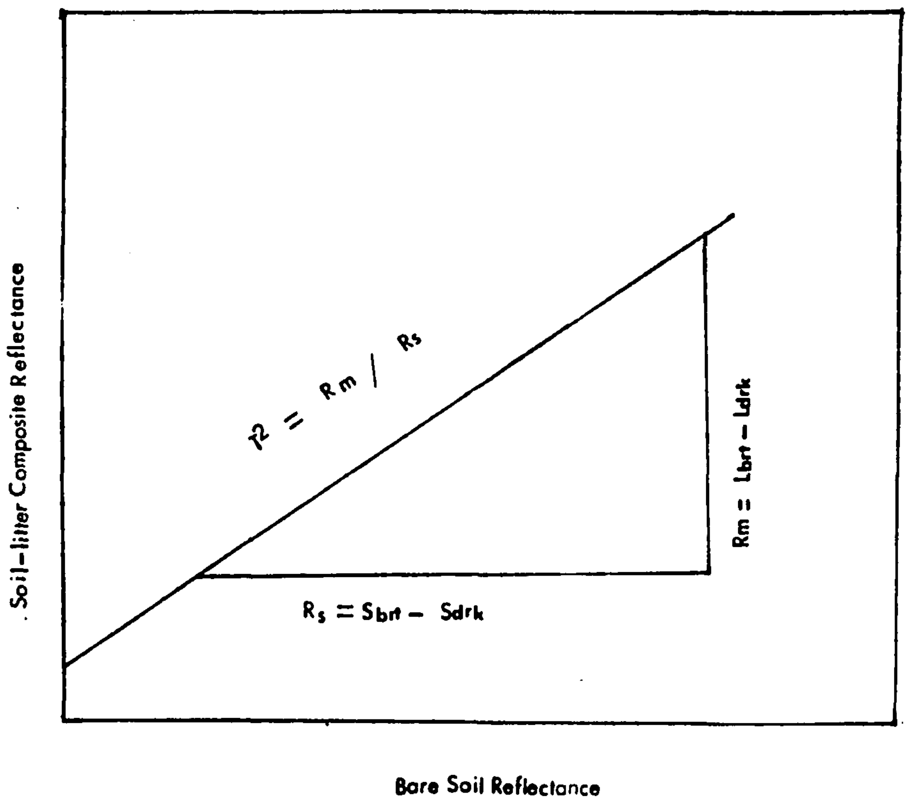


Fig. 9. Diagram for use in calculating the two-way flux penetration factor.

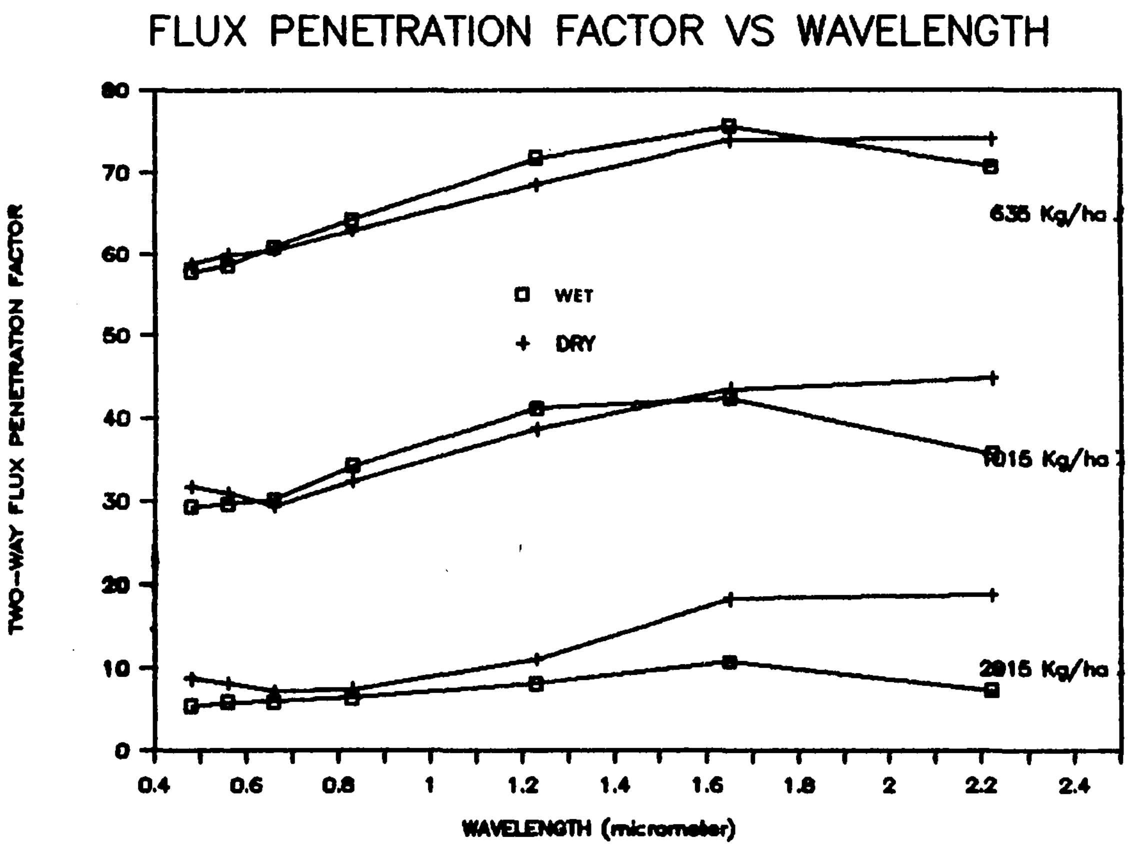


Fig. 10. Flux penetration factor as a function of wavelength.

this point the solar radiant flux is unable of further penetration of the litter cover thus, reflectance is no longer affected by the underlying soil background.This corresponds to the asymptotic spectral reflectance of Tucker (1977) and the R^{∞} (infinite reflectance) of Allan and Richardson (1968). This concept describes the point where an additional increase in litter biomass causes no measurable change in spectral response.

The relationship between spectral reflectance and litter biomass suggests the potential of using spectral techniques in biomass assessment. From equation (2):

$$R_m = R_s \quad T^2 \quad + \quad R_l$$

it appears that knowing bare soil reflectance (R_s) and litter two-way penetration factor (T^2), we can derive (R_l), litter reflectance from measured total reflectance (R_m) as follows:

$$R_l = R_m - R_s \quad T^2 \tag{4}$$

Litter reflectance can then be calibrated against known litter biomass. This combined with a better understanding of the bounding conditions of equation (2) may lead to a more useful quantitative assessment of litter biomass.

CHAPTER 4

LITTER AND VEGETATION INDICES

It is well established that vegetation assessment by remote sensing techniques is affected by soil spectral variability (Jackson et al., 1979; Huete et al., 1984; Hutchinson, 1982; Ezra et al., 1984). This problem seems particularly important in arid regions where the sparsity of the vegetation cover adds up to intrinsic variabilities of the soil medium. Vegetation indices were devised in an effort to minimize soil influences upon vegetation assessment. Vegetation indices can be classified into two main groups; the ratio and the orthogonal. In the preceding chapters of this study we showed how litter cover impacts soil spectral properties. In this chapter, our objective is to investigate litter cover effects on greenness as predicted by some ratio and orthogonal vegetation indices.

METHODOLOGY AND CALCULATION

The simplest of all vegetation indices are the ratio-based indices whereby reflectance in one spectral band is divided by reflectance in a second spectral band i.e., NIR/RED, the ratio of the near infrared to the red band and its derivative, the normalized difference (NDVI = (NIR - RED)/(NIR + RED)). The NIR and Red are preferred in vegetation studies due to their opposite sensitivity to green vegetation; the red region is characterized by strong chlorophyll absorption; the spectral responsitivity of this region is inversely related to the chlorophyll density. The NIR region on the other hand corresponds to the region of the spectrum where spectral reflectance is proportional to the green leaf density (Tucker, 1980). Thus, ratio combination of these two wavebands forms a strong vegetation index.

With orthogonal vegetation indices, however, the measure of greenness on a given point of the soil surface is determined by the distance from the point to a line of reference called the "soil line." The soil line is the image of bare soil data set plotted in NIR-RED-space. It is demonstrated that the trace view of a bare soil data set falls on almost a straight the line in the NIR-RED space (Kauth and Thomas, 1976). As vegetation grows on the soil surface, the spectral image of the point migrates upward with the orthogonal distance from the point to the line being a measure of the amount of green vegetation present on the soil surface. The two orthogonal vegetation indices are based on the same principle; they only differ in dimensionality. The Perpendicular vegetation Index (PVI) (Richardson and Wiegand, 1977) is a two-dimensional vector whereas the Green Vegetation Index (GVI) is a four-dimensional one.

In this study, the PVI was derived as described by Jackson et al. (1980). First, a soil line of the form

$$Y = a_0 + a_1 X \tag{5}$$

is derived by linear regression of NIR and Red bare soil reflectance where:

Y = bare soil NIR reflectance

X = bare soil Red reflectance

a_0 = Y-intercept

a_1 = slope

then given a point $M(X_i, X_i)$ (Fig. 11) in the NIR-Red waveband space, PVI is defined as the distance from the line to the point. This distance is geometrically expressed as follows (Lupsin, 1970): Rewriting equation (4): $R_1 = R_m - R_S T^2$ yields

$$AY_i - a_1 X_i - ao = 0 \quad (6)$$

Reducing (5) to its normal form yields:

$$(AY_i - a_1X_i - a_0) \sin \ / \ [+ (A^2 + a^2{}_1 - 2A^2{}_1)^2 \cos \ ] = 0 \quad (7)$$

$$PVI = (Ay_i - A_1X_i - a_0)\sin \ / \ (A^2 + a^2{}_1 - 2Aa_1)2 \cos \quad (8)$$

which, in the cartesian system reduces to:

$$PVI = (Ay_i - a_1X_i - a_0) \ / \ (A^2 + a^2{}_1)^{1/2} \quad (9)$$

where

$A = 1$

and the subscript i indicates that X_i and Y_i are coordinates of a vegetation point. Equation (8) can therefore be rewritten as follows:

$$PVI = (Y_i - a_1X_i - a_0) \ / \ [1 + (-a_1)^2 \ ]^{1/2} \quad (10)$$

solving (8) for the three soils used in this study yields:

$$PVI = 1.518 \ Y_i - 1.734 \ X_i - 2.802 \quad (11)$$

The diagram in Figure 11 depicts the soil line and the perpendicular vegetation index.

Other indices: Green Vegetation Index (GVI), Brightness (SLI), and Yellowness were derived following the algebraic n-space procedure described by Jackson (1983) whereby, unit vector elements are calculated for each feature in each waveband. Coefficients thus computed are multiplied by corresponding reflectance before being

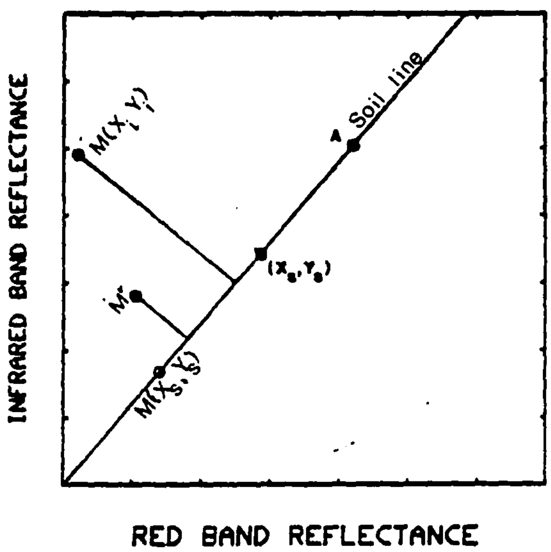


Fig. 11. Diagram depicting the soil line and the perpendicular vegetation index.

derived global features based on a mean soil line. For each specific soil, the reflectance of the soil line range was defined between the dry and the wet substrate whereas for the global data set, this range was provided by the brightest (dry Superstition sand) and the darkest (wet Cloversprings) soils of the data set. The resulting vector elements are presented in Table 3. The yellow point was obtained by stacking all three litter covers thus forming a fourth cover of 4450 Kg/ha density. The green point used in the study was a dense wheat canopy.

It has been demonstrated that the universal soil line assumption may lead to substantial errors in green vegetation assessment (Huete et al., 1984; Ezra et al., 1984). In this study, although we have derived greenness indices based on the mean soil line as well as those based on site specific soil lines, we will first limit ourselves to analyzing the latter without reference to the first. Because litter cover exhibits a soil-like spectral behavior, each individual soil has in reality 4 different background soil lines: one bare soil line and 3 "litter lines." In this situation, the bare soil line may be considered as the mean soil line with regard to the litter lines. Figures 12, 13 and 14 show the three soils plotted in the n-space. It can be seen from those figures that the greenness dynamic ranges were 56 and 44.7 for the Cloversprings and Whitehouse respectively. On the other hand, the light soil (Superstition) exhibited a shorter greenness range of 44. An early study by Huete et al. (1985) showed that lighter bare soils tend to produce lower greenness index values (GVI). However, the same authors demonstrated in 1987 that when

Table 3. Derived coefficients of selected vegetation indices: Cloversprings.

COEFFICIENTS

CLOVERSPRINGS

BRIGHT	0.0722	0.0982	0.1409	0.2051	0.4133	0.5539	0.6675
GREEN	-0.0041	0.0083	-0.0612	0.8547	0.3492	-0.1359	-0.03539
YELL.	0.4196	0.5103	0.6368	-0.0875	-0.0258	0.1645	-0.3547

WHITEHOUSE

BRIGHT	0.0457	0.0817	0.1438	0.1936	0.3307	0.5677	0.7081
GREEN	-0.031	-0.0455	-0.2385	0.8888	0.2945	-0.1416	-0.2123
YELL.	0.6299	0.6046	0.3603	0.1083	-0.0588	0.1183	-0.2806

SUPERSTITION

BRIGHT	0.137	0.1756	0.2221	0.2606	0.36	0.5185	0.6593
GREEN	-0.1147	-0.1808	-0.3517	0.827	0.3005	-0.132	-0.1967
YELL	0.3748	-0.0156	-0.4927	-0.1208	-0.0518	0.6813	-0.3675

GLOBAL

BRIGHT	0.1711	0.2467	0.3305	0.3837	0.4325	0.4753	0.4903
GREEN	-0.07777	-0.0987	-0.2082	0.7901	0.2819	-0.2249	-0.4318
YELL	0.3986	0.3483	0.3143	-0.1521	0.2801	0.2924	-0.7153

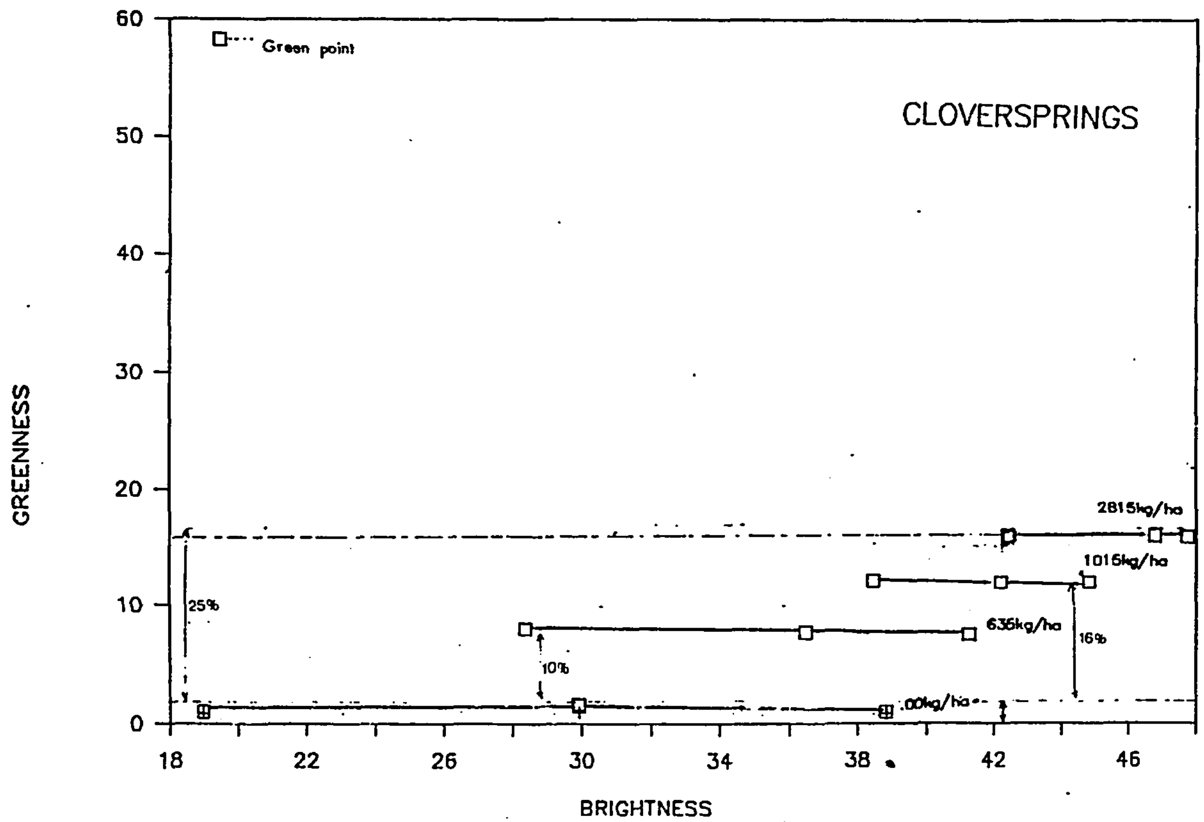


Fig. 12. Greenness as a function of brightness (Cloversprings soil).

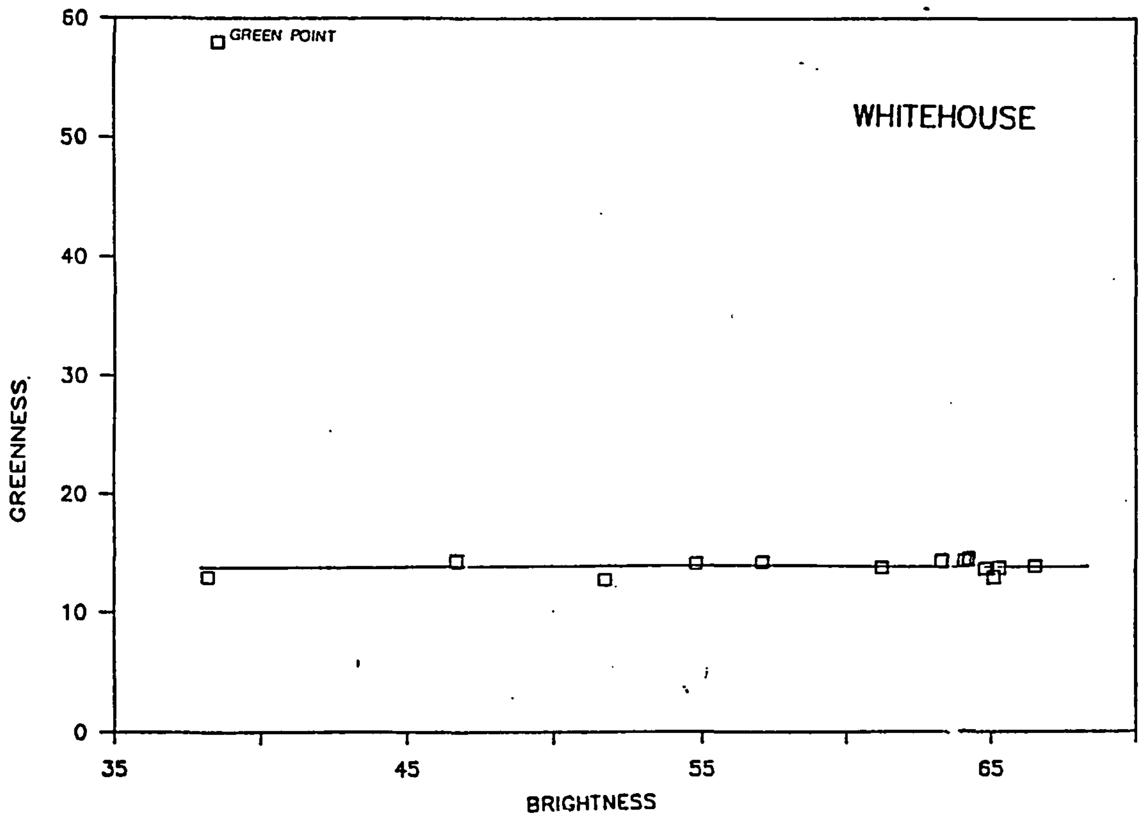


Fig. 13. Greenness as a function of brightness for various litter densities: Whitehouse soil.

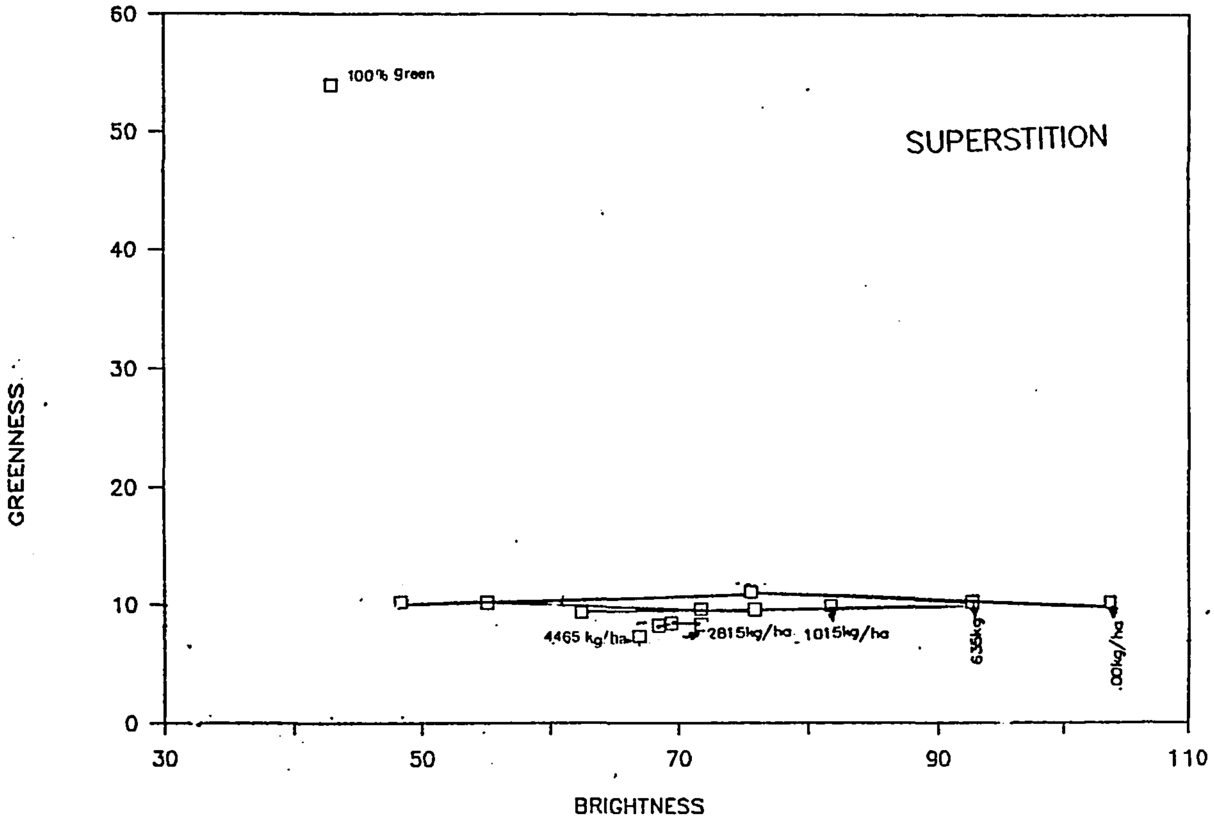


Fig. 14. Relationship between greenness for various levels of litter cover: Superstition soil.

overlain by the same amount of vegetation lighter soils tend to have the longer GVI dynamic range than dark ones. This bare soil-like spectral behavior of litter cover seems to suggest that soil and litter are spectrally additive. Litter unlike vegetation, may affect the greenness index either positively or negatively owing to the magnitude and the "direction" of the contrast between litter cover and the underlying soil background (see Table 2). In case of a strong and positive contrast, litter cover amplifies the total range of GVI values; on the contrary if the contrast is strong and "negative," litter cover decreases the overall GVI range. On the Whitehouse background where the contrast between soil and litter cover was virtually nil, litter cover seems to have no noticeable influence on the GVI index; on this background, soil and litter lines are confused in almost one global line (Fig. 13). On the contrary, the Cloversprings substrate exhibited a very substantial litter-induced noise in proportion of 10%, 16%, and 25% for respectively 635, 1015, and 2815 Kg/ha litter cover density (Fig. 12). On the Superstition background, because the contrast between the substrate and litter cover is "negative," soil and litter-induced greenness tend to cancell each other in such a way that for the same amount of vegetation, a mulched Superstition soil will have lower GVI-predicted-greenness in comparison to the same soil without litter cover (Fig. 14). In summary, litter cover by increasing or decreasing GVI greenness range may cause an overestimation or under estimation of GVI-based greenness depending upon the contrast between the cover and the underlying soil substrate.

Figures 15, 16, and 17 show global plots of GVI and yellowness on the Superstition-Cloversprings soil line. From these figures it can be seen that bare soils circumscribe mulched ones. This leads to the conclusion that soil variability and moisture have a much stronger effect on brightness, greenness, and yellowness than soils covered with litter. In other words, the presence of litter dampens soil spectral variances attributed to soil type and moisture.

Theoretically, all orthogonal indices are perpendicular to each other. Thus, a plot of GVI vs Yellowness for a data set containing no green vegetation; should yield a straight line with a slope of (0). From Figure 16 it can be seen that this did not hold true for the soils used in this study. The relationship appears to be soil and litter-dependent. On dark substrates (wet Whitehouse, wet Superstition and dry and moist Cloversprings), an increase in litter cover density resulted in an increases of both greenness and yellowness. On lighter substrate however, this trend was apparent only at low litter density (635 Kg/ha). At higher litter density, greenness decreased with increasing yellowness. Figures 18, 19, and 20 present the perpendicular vegetation index (PVI), the normalized difference vegetation indice (NDVI) and the near infrared to red ratio (NIR/RED) plotted against litter density for each test soil. From these figures it appears that NDVI and NIR/RED were sensitive to increasing litter density as they decreased with increasing litter cover. Based on the normalized difference and the near infrared to red ratio, darker soils (Whitehouse and Cloversprings) appeared "greener" than the light one (Superstition sand). This agrees with previous studies by Colwell

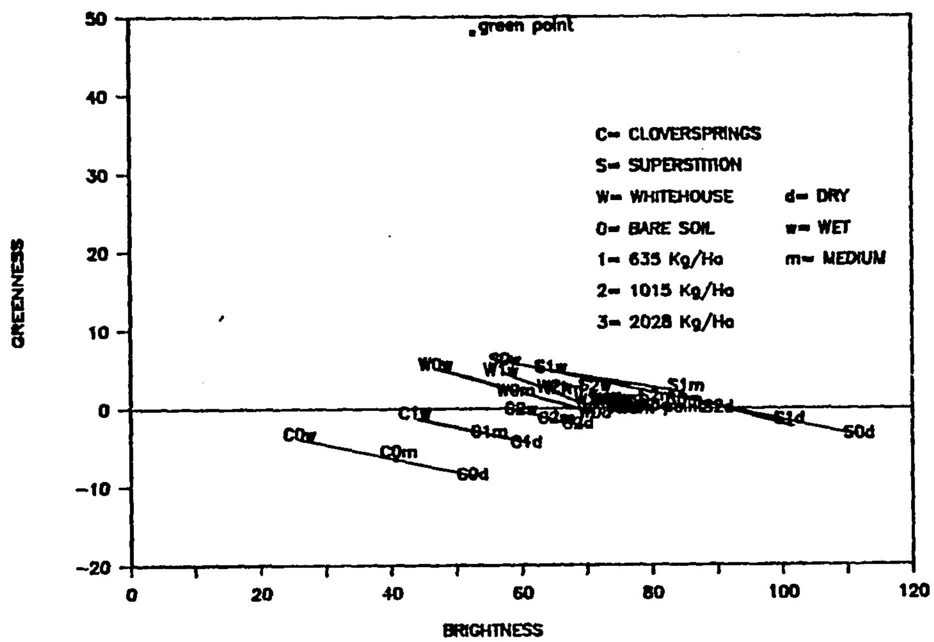


Fig. 15. Relationship between greenness and brightness for all soils at all litter densities.

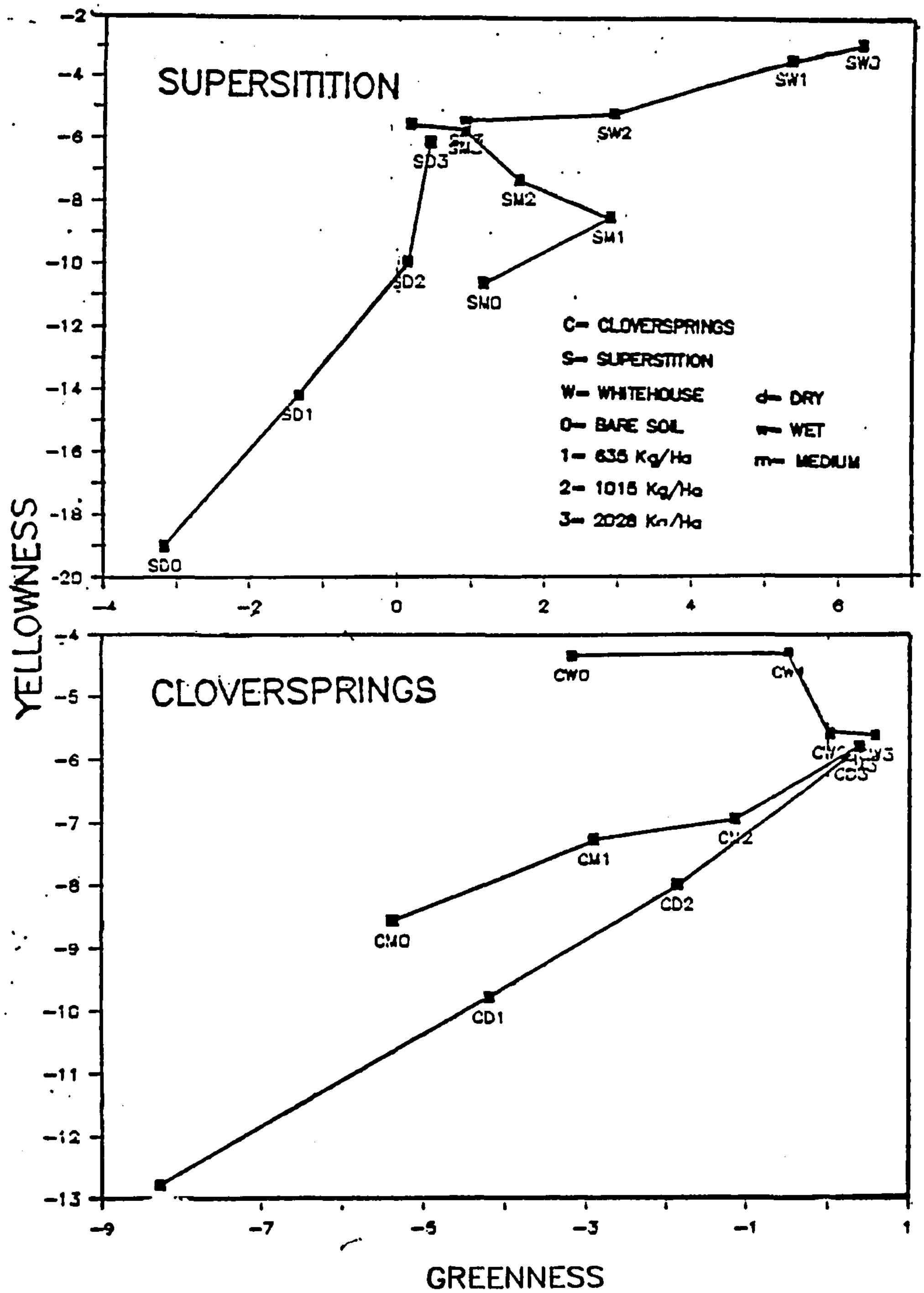


Fig. 16. Yellowness as a function of brightness for all soils under various little densities.

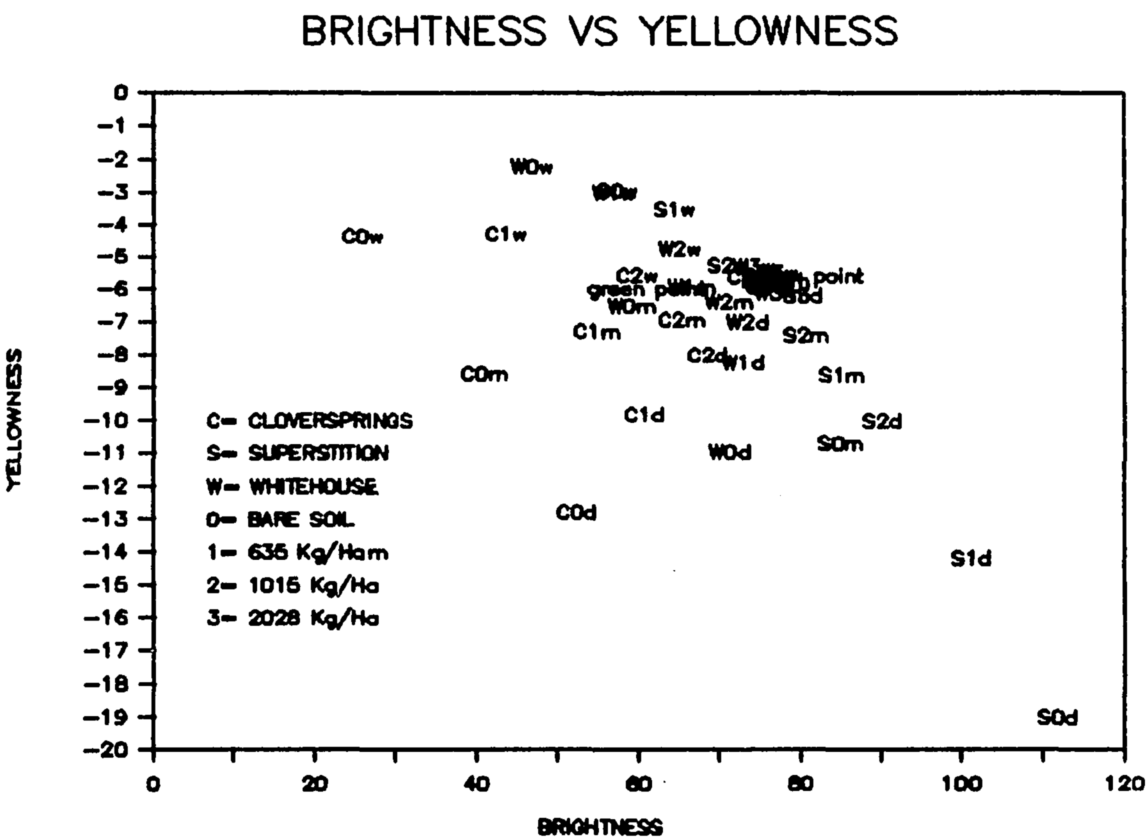


Fig. 17. Relationship between yellowness and greenness for Superstition and Cloversprings at all litter densities.

(1973); Elvidge and Lyon (1985); and Huete et al. (1985) where it wasshown that dark soils produce higher NDVI and NIR/RED values. The PVI maintained a steady decreasing trend with increasing litter density on the Cloversprings and the Whitehouse substrates. However, the same could not be said about the behavior of this index on the Superstition background where the trend was rather unpredictable. It appears however that PVI-predicted greenness is lower on darker soils at higher litter cover densities (1015, 2815, and 4450 Kg/ha) (see Figs. 18, 19, and 20). In all cases soil-induced vegetation index variations were reduced with the presence of litter.

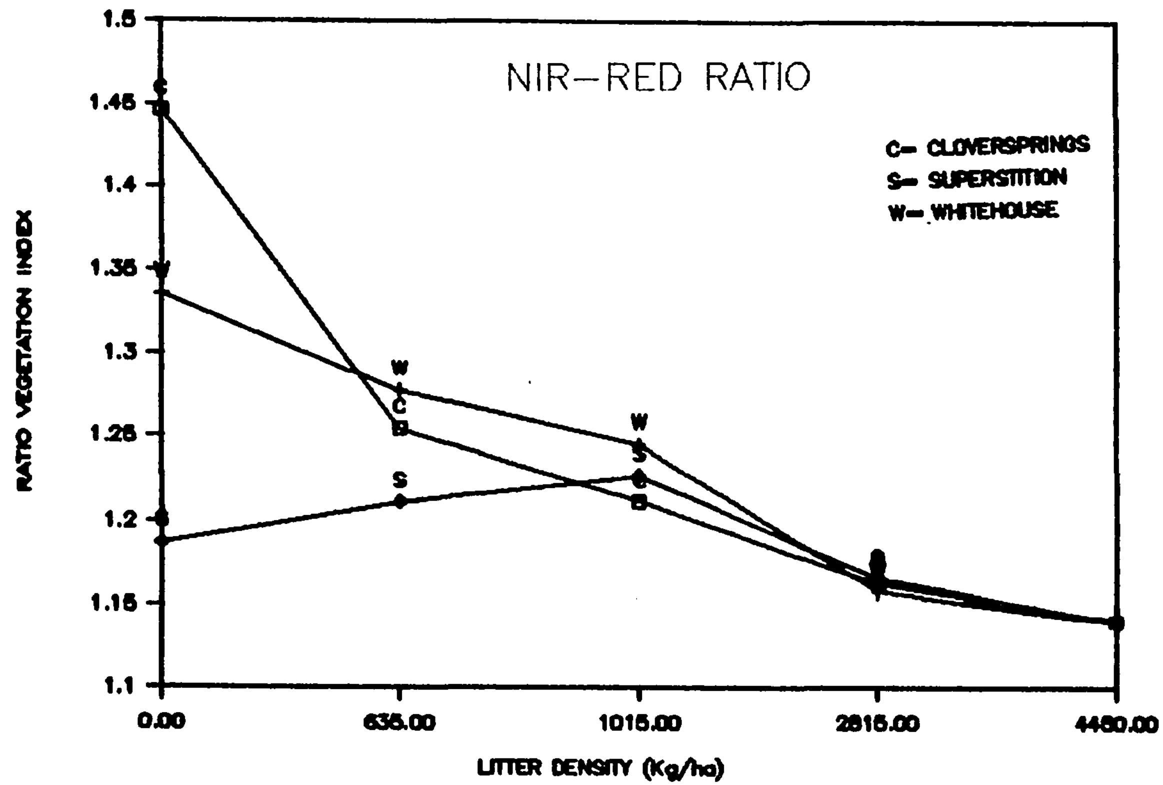


Fig. 18. NIR/RED ratio as functions of litter cover density: Whitehouse soil.

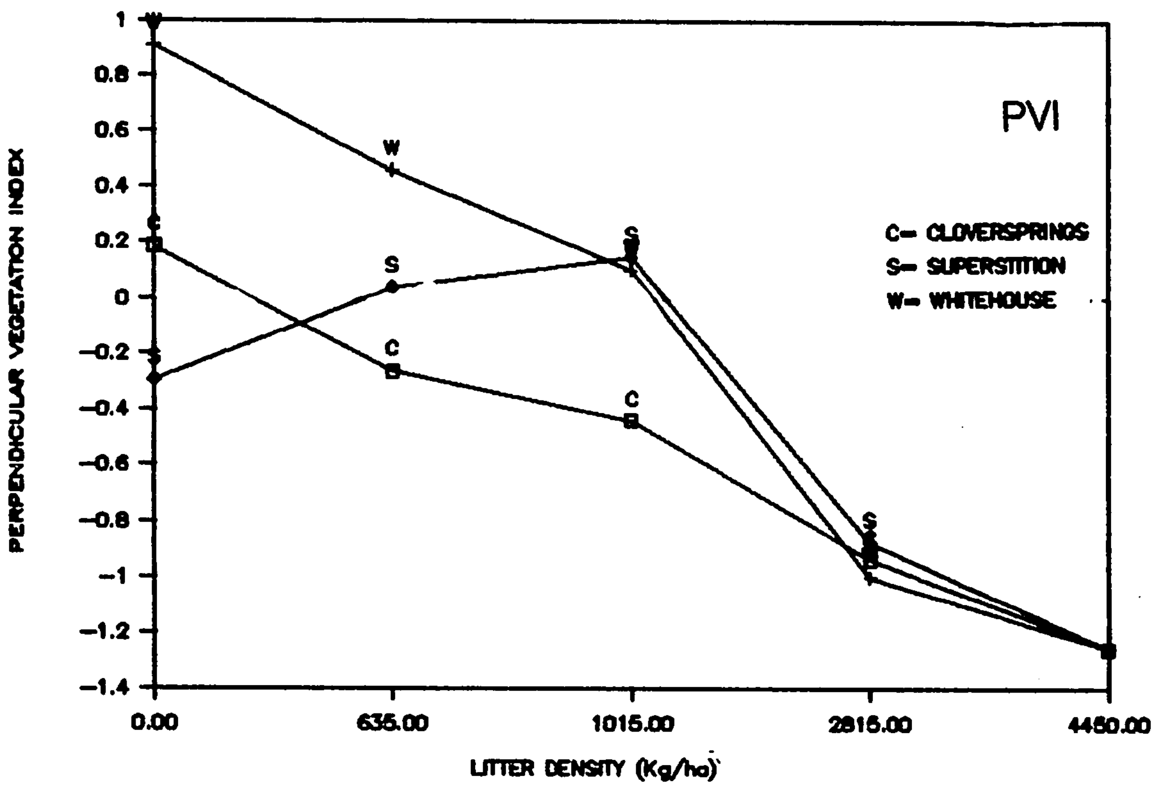


Fig. 19. Perpendicular vegetation index as function of litter density for all soils.

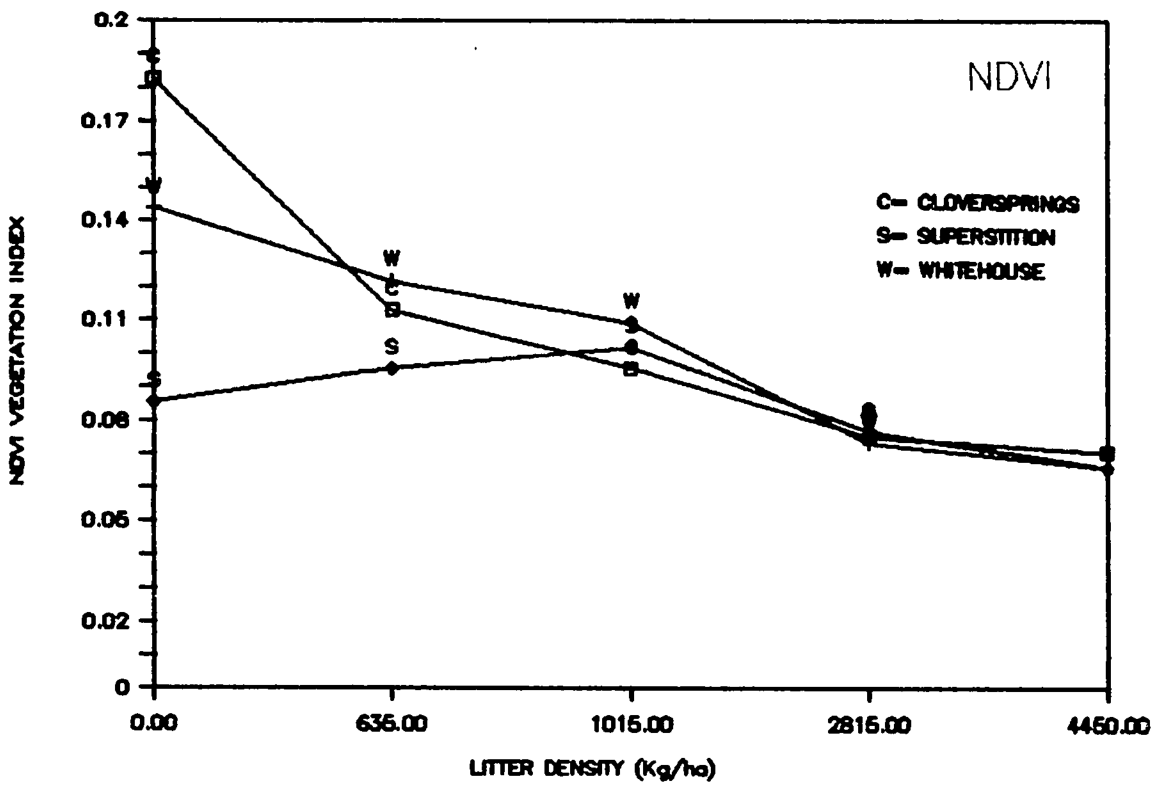


Fig. 20. Normalized difference as a function of litter density.

CHAPTER 5

SUMMARY AND CONCLUSIONS

A study of litter cover effects upon soil spectral behavior was conducted using three spectrally different soil backgrounds that were covered with increasing amounts of litter. Radiometric measurements were taken with a Barnes multi-modular 8-band radiometer.

Results showed that:

a) Litter cover exhibits a soil-like spectral response pattern with a steady increase throughout the photographic and the near infrared spectrum followed by a peak and a gradual decrease in the middle infrared region.

b) Soil-litter composite reflectance appears to be dependent upon the degree of contrast between the soil substrate and the litter cover. Whenever litter brightness was greater than the soil brightness, composite reflectance increased. Reflectance decreased when the above situation was reversed.

c) Soil-litter composite reflectance is a linear function of soil reflectance which can be easily modeled. This suggests that remote sensing techniques can be used in qualitative and semi-quantitative studies of soil litter cover. Quantitative evaluation of litter is limited due to the asymptotic nature of litter reflectance. It would be interesting to further investigate this phenomenon in order to establish the boundaries and the thresholds imposed upon the use of spectral approaches to quantitative estimation of litter cover.

d) All vegetation indices were litter-sensitive. Ratio indices predicted higher greenness for darker soils whereas orthogonal indices predicted higher greenness on lighter substrates. GVI predicted greenness like soil-litter reflectance, seems to be soil dependent in so far as it is strongly affected by the magnitude and the direction of the contrast between the soil substrate and litter cover.

e) On a global scale, soil variability seems to affect GVI-predicted greenness to a greater degree than litter cover differences. However, for the other indices analyzed in this study, litter-induced variance within a given soil type may exceed soil-induced variances among soil types (see Figs. 18, 19, and 20).

APPENDIX A

REFLECTANCE DATA FOR ALL SOILS

SUPERSTITION

	MMR1	MMR2	MMR3	MMR4	MMR5	MMR6	MMR7
DRY							
0.00	16.09	23.24	31.39	37.25	48.86	55.81	54.98
635.00	14.95	20.86	27.70	33.54	45.82	52.17	46.35
1015.00	13.83	18.75	24.43	29.97	41.76	47.91	38.23
2815.00	13.35	17.79	22.68	26.42	36.94	43.75	31.21
WET							
0.00	8.37	13.35	18.88	22.57	28.58	26.60	17.84
635.00	10.59	15.24	20.14	24.19	31.69	31.17	21.19
1015.00	11.62	15.78	20.64	24.99	33.75	36.52	26.25
2815.00	12.99	17.18	21.86	25.52	35.64	41.67	29.30
MOIST							
0.00	12.62	19.10	25.64	29.63	38.31	41.20	36.07
635.00	13.03	18.57	25.08	30.20	39.99	42.46	33.88
1015.00	12.63	17.26	22.62	27.42	37.65	42.12	31.87
2815.00	12.98	17.11	21.98	25.81	36.21	42.26	29.89
4465.00	13.28	17.15	21.57	24.57	34.35	40.47	29.12
Green	2.51	4.36	2.13	57.11	39.49	17.62	5.16

CLOVERSPRINGS

DENSITY Kg/ha	MMR1	MMR2	MMR3	MMR4	MMR5	MMR6	MMR7
				DRY			
0.00	3.44	4.83	6.99	10.11	23.46	30.74	31.86
635.00	7.65	10.08	12.84	16.11	27.61	33.27	30.00
1015.00	10.12	13.27	17.06	20.66	31.33	37.32	30.02
2815.00	12.66	16.71	21.23	24.67	34.89	41.06	29.53
				WET			
0.00	1.38	2.03	2.97	4.26	11.67	14.94	12.82
635.00	6.48	8.46	10.52	12.67	20.10	22.57	17.48
1015.00	9.40	12.27	15.94	19.06	27.22	31.47	24.01
2815.00	12.38	16.26	20.71	24.16	33.77	39.55	28.36
				MOIST			
0.00	2.31	3.48	5.20	7.72	18.85	23.88	22.73
635.00	7.59	9.50	11.81	14.55	25.28	29.77	25.08
1015.00	9.84	12.88	16.50	19.86	29.68	34.96	27.47
2815.00	12.66	16.51	21.01	24.53	34.79	40.81	29.26
4465.00	13.28	17.15	21.57	24.57	34.35	40.47	29.12
Green	2.51	4.36	2.13	57.11	39.49	17.62	5.16

Whitehouse (B)

DENSITY Kg/ha	MMR1	MMR2	MMR3	MMR4	MMR5	MMR6	MMR7
DRY							
0.00	4.31	8.58	16.68	22.28	35.02	39.07	33.52
635.00	8.32	12.28	18.74	23.94	35.68	38.81	30.63
1015.00	10.27	14.01	19.43	24.19	34.99	39.48	29.68
2815.00	12.74	16.80	21.27	24.62	34.43	40.98	29.45
WET							
0.00	3.08	6.38	12.81	17.07	26.12	23.79	14.46
635.00	7.50	10.96	16.26	20.51	29.42	28.45	18.70
1015.00	9.86	13.35	18.27	22.46	31.38	33.48	23.88
2815.00	12.74	16.79	21.34	24.81	34.07	39.35	28.01
MOIST							
0.00	3.50	7.14	14.07	19.19	30.71	31.91	23.97
635.00	7.89	11.49	17.24	22.15	33.33	35.00	25.64
1015.00	10.16	13.87	18.83	23.18	33.62	37.84	28.03
2815.00	12.80	16.83	21.44	24.84	35.24	41.70	30.15
4465.00	13.28	17.15	21.57	24.57	34.35	40.47	29.12
Green	2.51	4.36	2.13	57.11	39.49	17.62	5.16

APPENDIX B

VEGETATION INDICES:GLOBAL SET

WHITEHOUSE

DENSITY Kg/ha	BRIGHT	GREEN	YELLOW	PVI
		DRY		
0.00	67.07	-0.44	-10.95	0.91
635.00	68.73	1.26	-8.22	0.46
1015.00	69.37	1.05	-7.00	0.10
2815.00	71.61	0.15	-5.87	-1.00
		WET		
0.00	42.58	5.72	-2.19	0.39
635.00	52.65	4.98	-3.02	0.06
1015.00	60.83	2.86	-4.74	-0.17
2815.00	70.07	1.17	-5.33	-0.93
		MOIST		
0.00	54.58	2.39	-6.51	0.84
635.00	62.00	2.62	-5.93	0.41
1015.00	66.55	1.10	-6.37	-0.11
2815.00	72.80	0.04	-6.10	-0.98
4465.00	71.43	0.20	-5.59	-1.26
GREEN	52.11	49.00	-5.95	34.80

SUPERSTITION

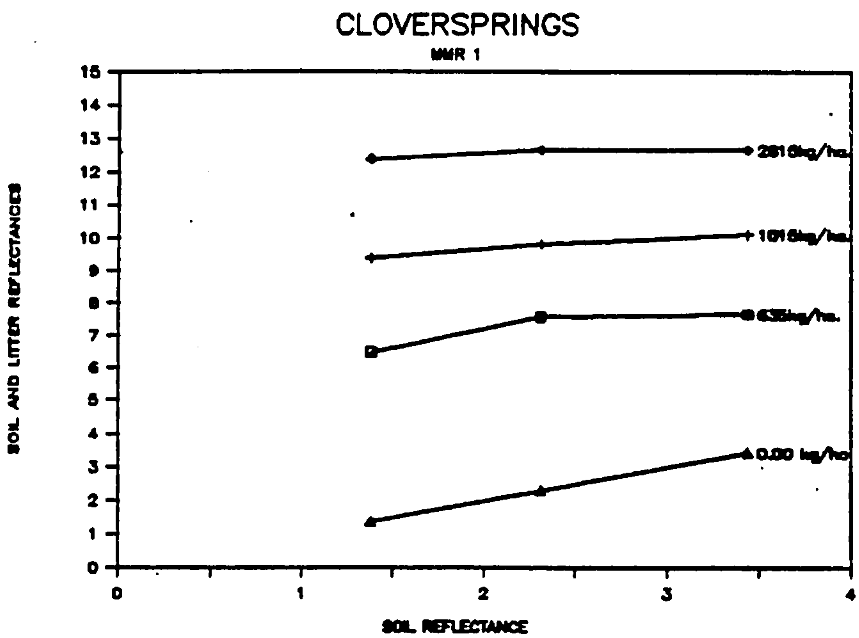
DENSITY Kg/ha	BRIGHT	GREEN	YELLOW	PVI
		DRY		
0.00	107.77	-3.17	-19.01	-0.29
635.00	97.07	-1.32	-14.22	0.04
1015.00	86.14	0.16	-9.98	0.15
2815.00	76.38	0.46	-6.18	-0.87
		WET		
0.00	53.38	6.30	-2.93	-0.55
635.00	60.42	5.37	-3.52	-0.43
1015.00	67.12	2.95	-5.26	-0.28
2815.00	73.06	0.93	-5.51	-0.85
		MOIST		
0.00	80.55	1.16	-10.66	-0.99
635.00	80.78	2.89	-8.59	-0.19
1015.00	76.35	1.65	-7.38	-0.17
2815.00	74.01	0.91	-5.73	-0.75
4465.00	71.43	0.20	-5.59	-1.26
Green	52.11	49.00	-5.95	34.80

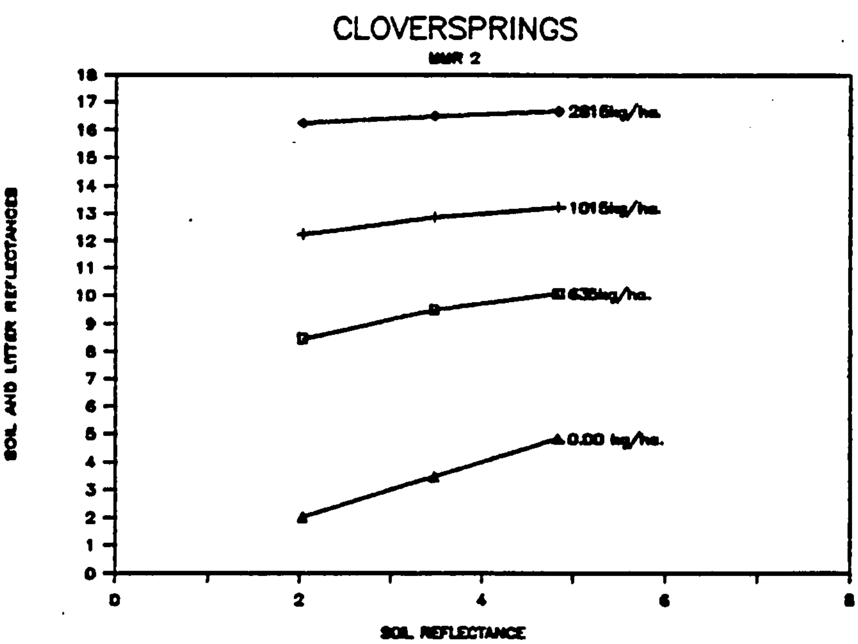
CLOVERSPRINGS

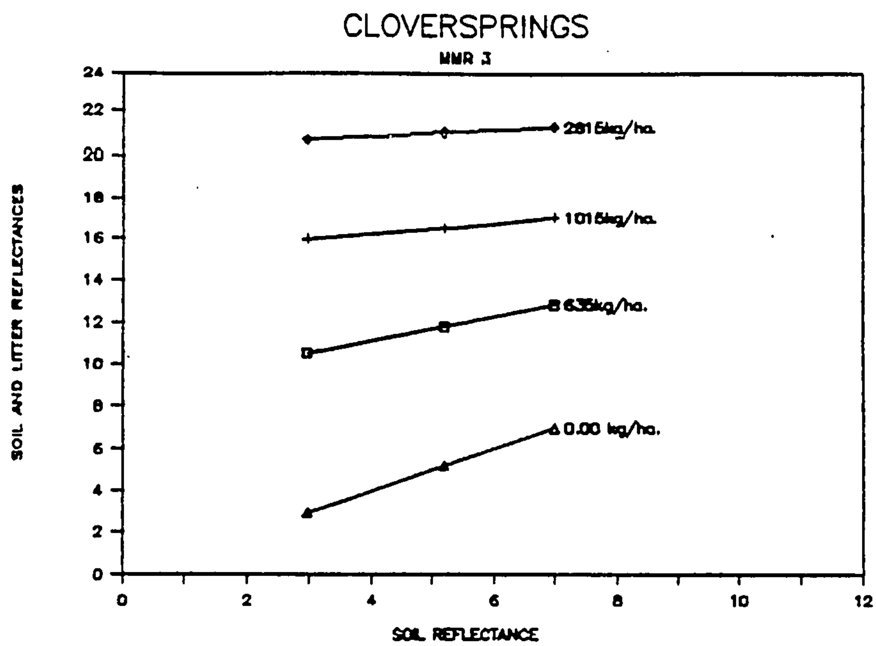
DENSITY Kg/ha	BRIGHT	GREEN	YELL	NIR/RED	NDVI	PVI
			DRY			
0.00	38.83	0.98	0.83	1.45	0.18	-5.77
635.00	41.27	7.54	9.56	1.25	0.11	-7.20
1015.00	44.82	11.93	15.17	1.21	0.10	-8.11
2815.00	42.42	16.03	21.07	1.16	0.07	-9.29
			WET			
0.00	18.97	0.98	0.83	1.43	0.18	-5.76
635.00	28.35	7.99	9.87	1.20	0.09	-7.23
1015.00	38.47	12.11	15.03	1.20	0.09	-8.09
2815.00	42.48	15.85	20.62	1.17	0.08	-9.15
			MOIST			
0.00	29.91	1.59	0.92	1.48	0.20	-5.64
635.00	36.48	7.67	9.92	1.23	0.10	-7.23
1015.00	42.24	11.92	15.11	1.20	0.09	-8.10
2815.00	46.78	16.01	20.90	1.17	0.08	-9.19
4465.00	47.73	15.96	21.84	1.14	0.07	-9.62
Green	19.47	58.28	0.83	26.81	0.93	24.80

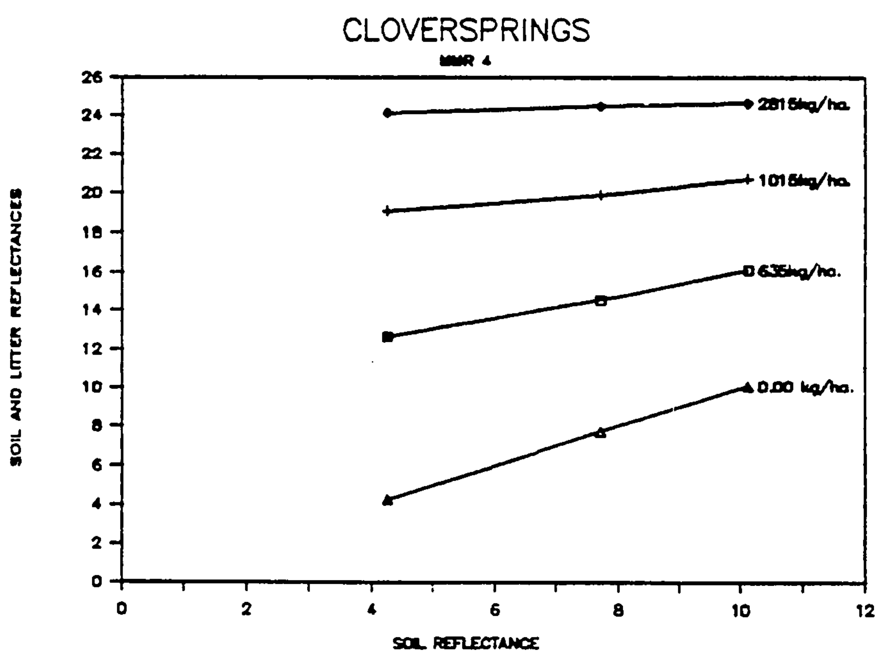
APPENDIX C

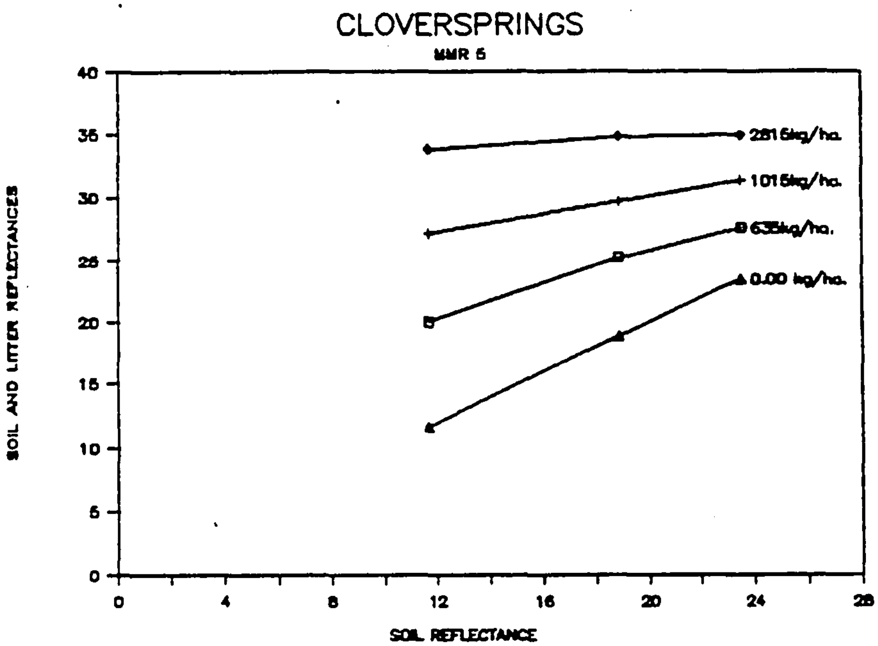
SOIL-LITTER REFLECTANCE AS FUNCTION OF SOIL REFLECTANCE FOR ALL MMR 7 BANDS

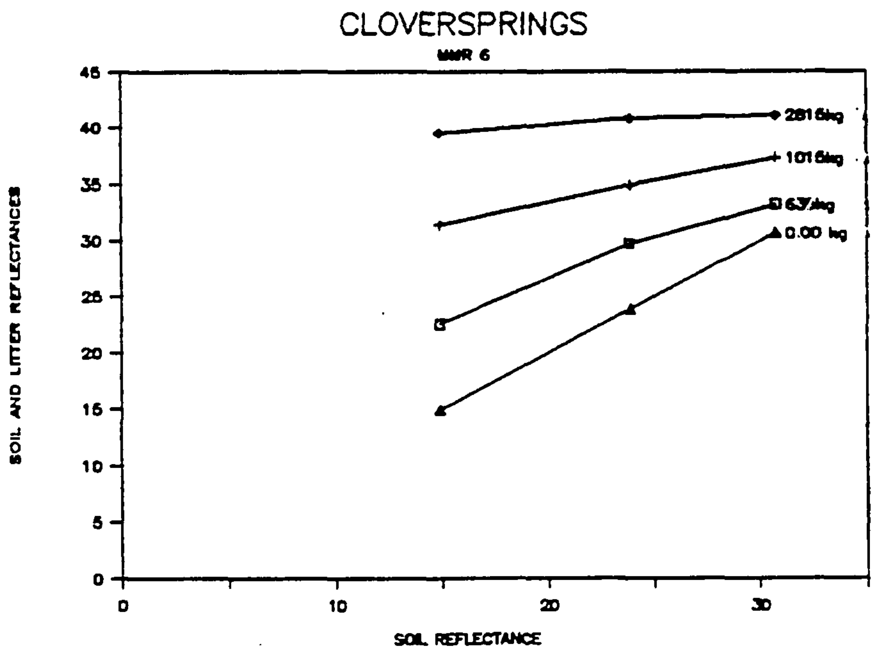

CLOVERSPRINGS
MMR 1
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2816kg/ha.
1016kg/ha.
635kg/ha.
0.00 kg/ha
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

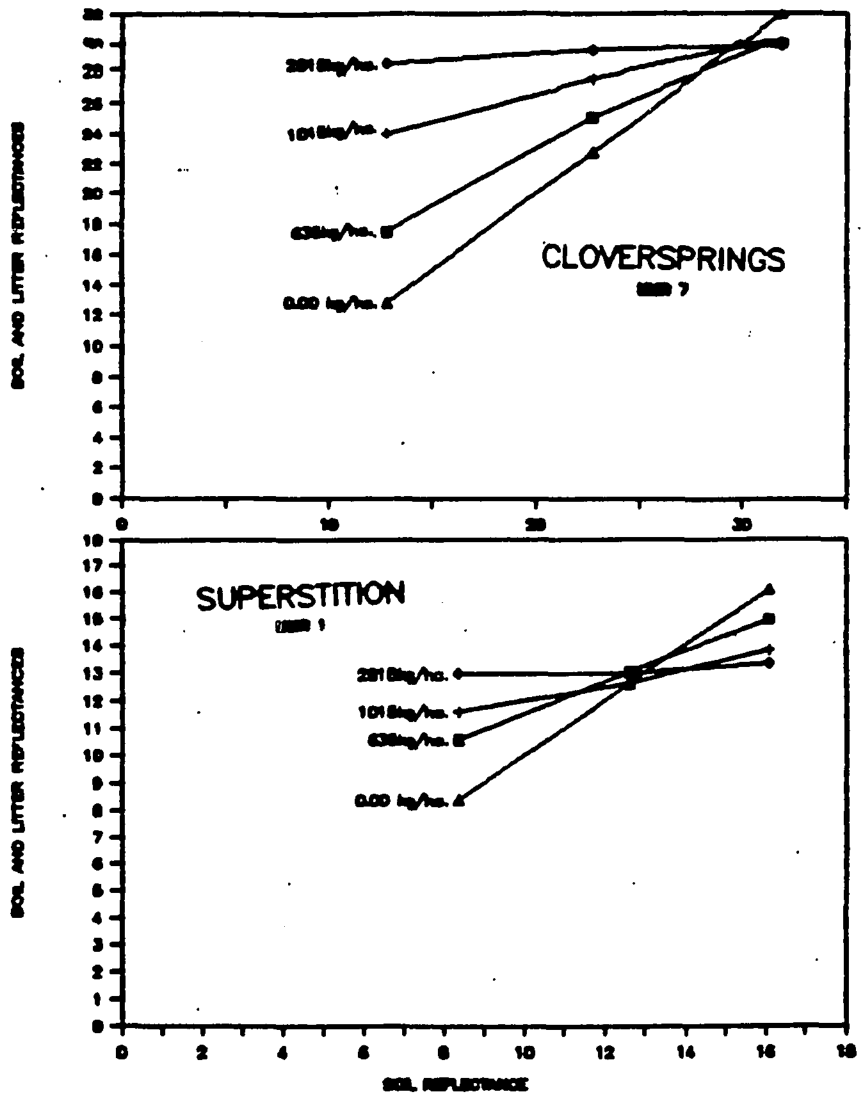

CLOVERSPRINGS
MMR 2
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2816kg/ha.
1016kg/ha.
635kg/ha.
0.00 kg/ha.
0
2
4
6
8
1
3
5
7
9
10
11
12
13
14
15
16
17
18

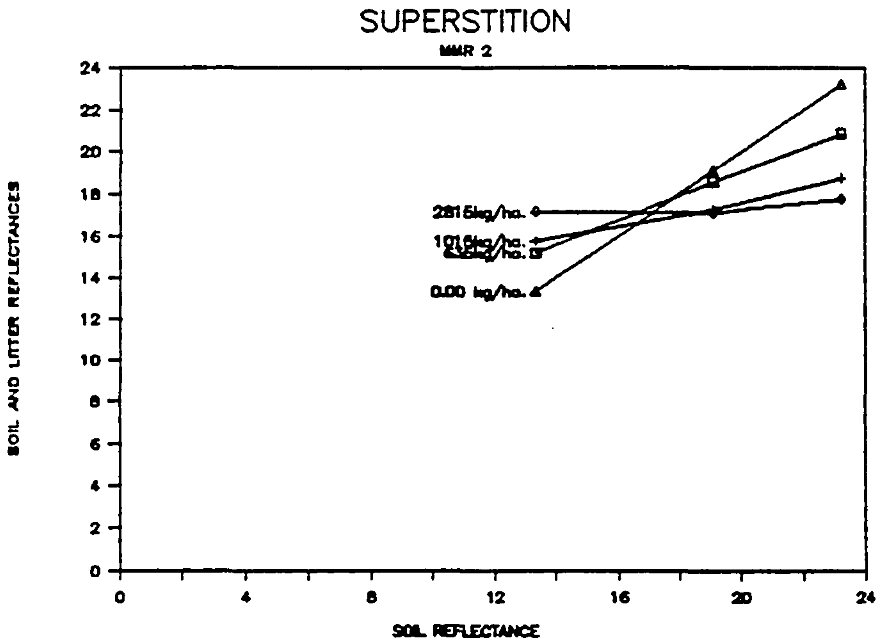

CLOVERSPRINGS
MMR 3
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.

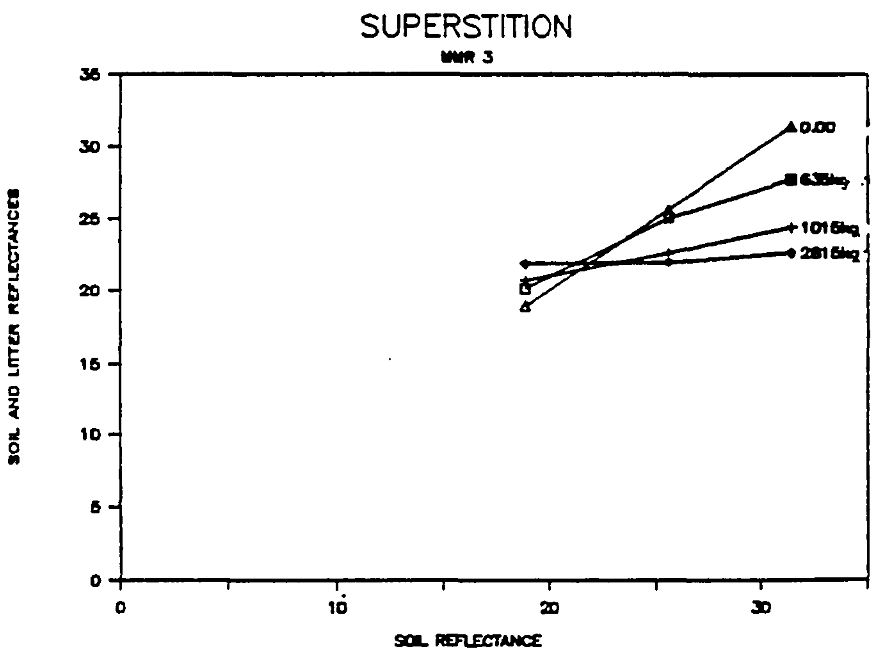

CLOVERSPRINGS
MMR 4
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.

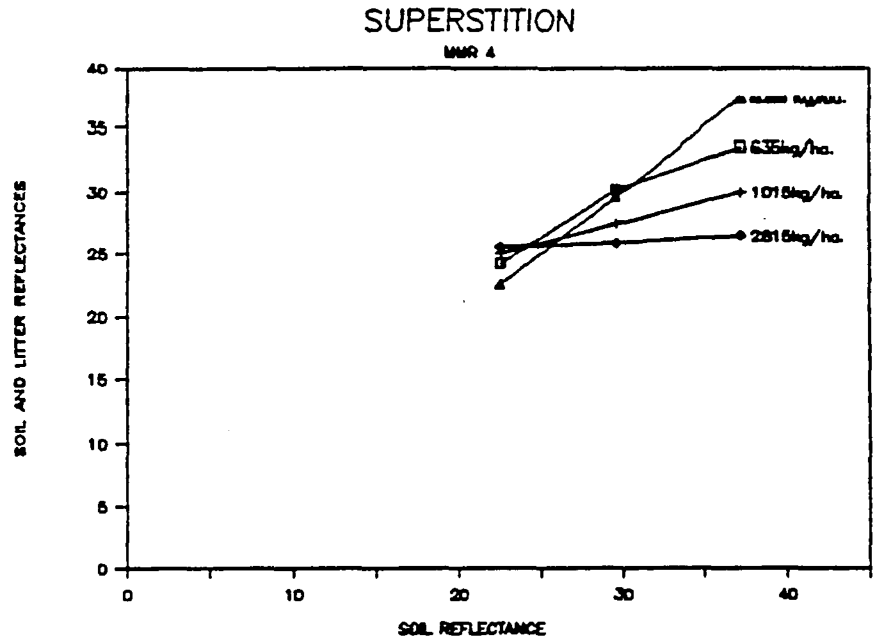

CLOVERSPRINGS
MMR 5
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE

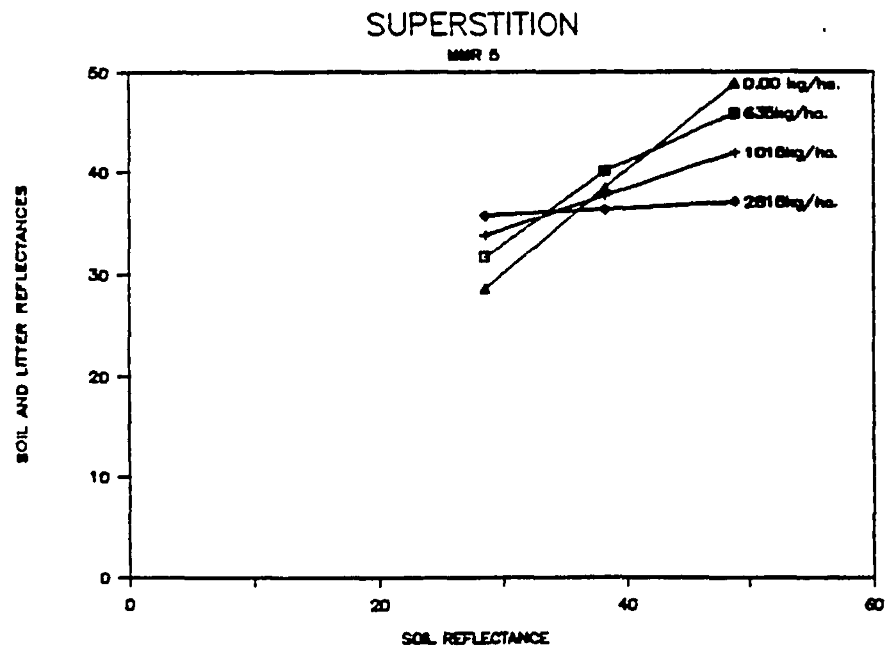

CLOVERSPRINGS
MMR 6
2815kg
1015kg
0.00 kg
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE

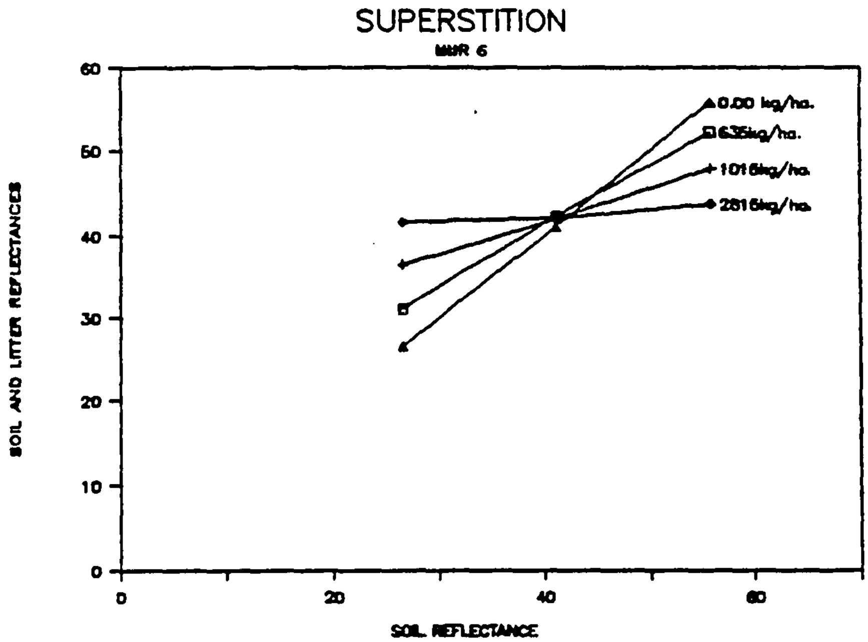

CLOVERSPRINGS
SUPERSTITION
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
0.00 kg/ha.

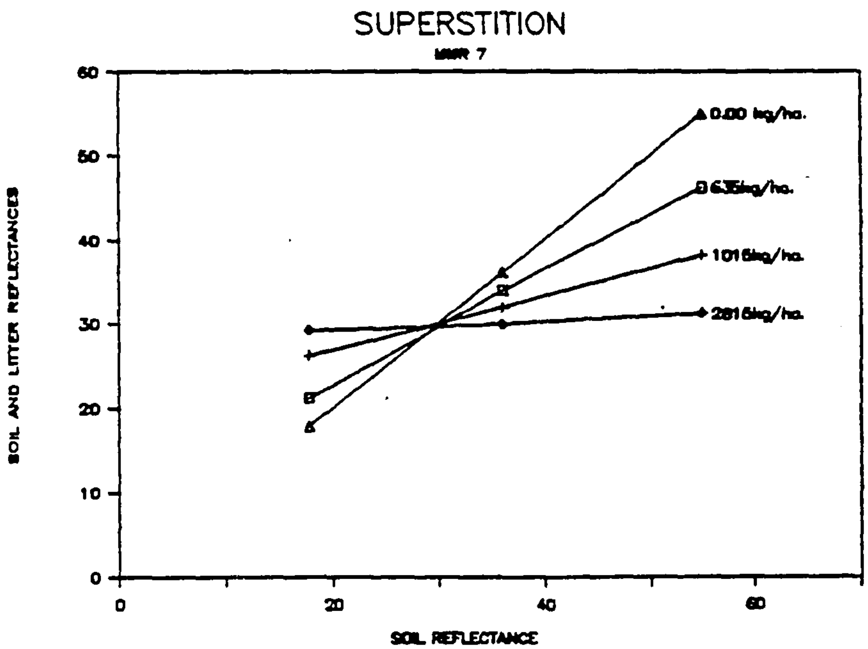

SUPERSTITION
MMR 2
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.

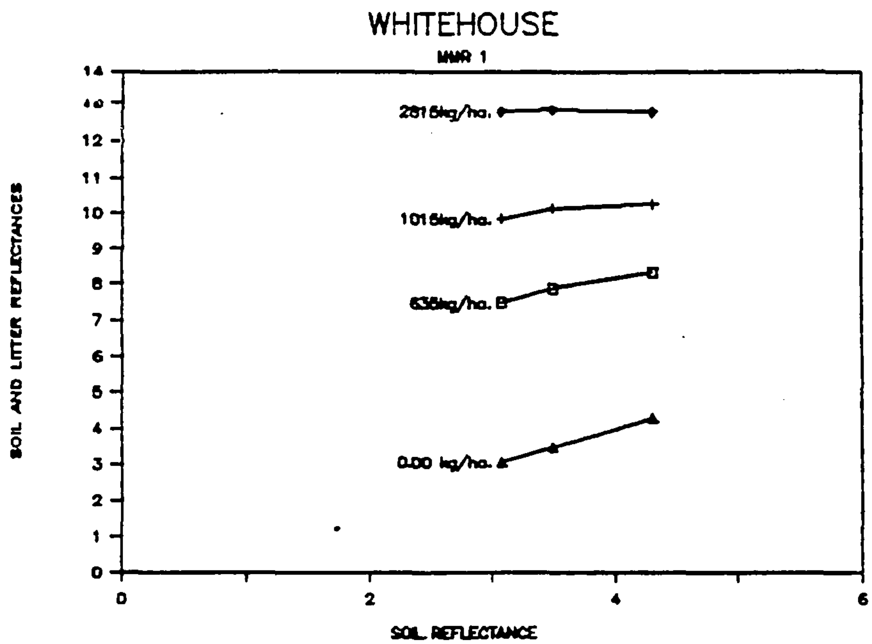

SUPERSTITION
MMR 3
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
0.00
635kg
1015kg
2815kg

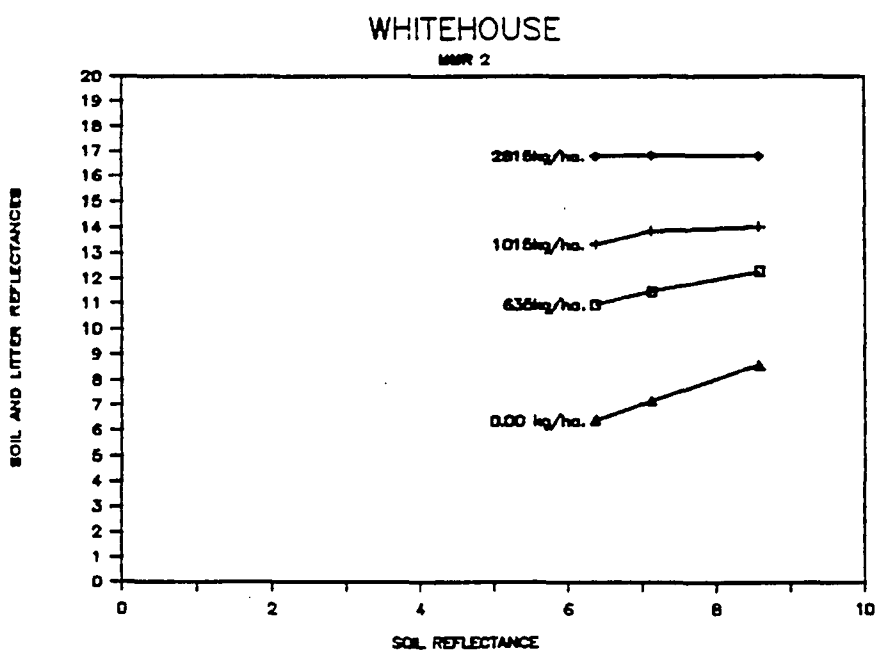

SUPERSTITION
MMR 4
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
635kg/ha.
1016kg/ha.
2816kg/ha.

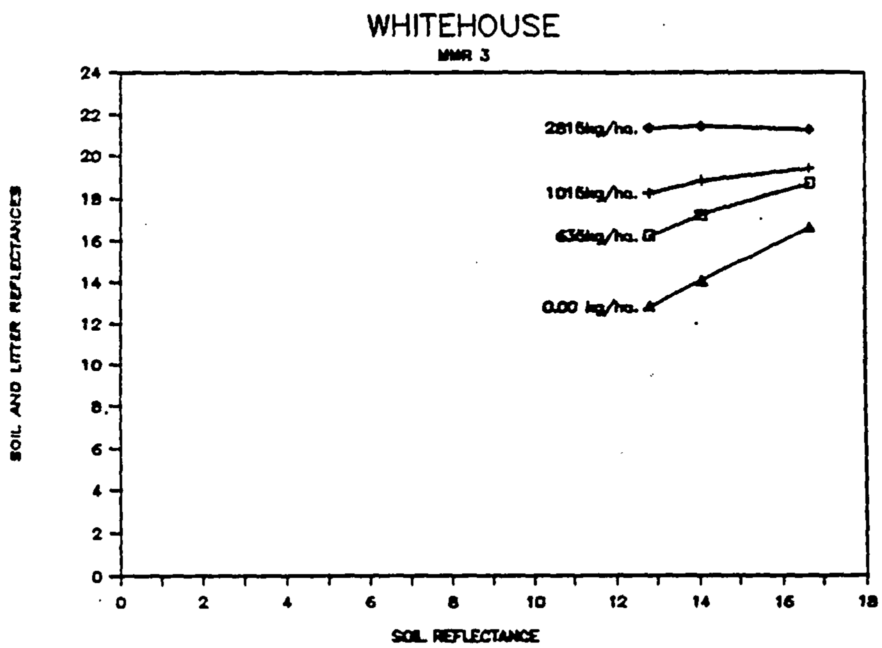

SUPERSTITION
MMR 5
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
0.00 kg/ha.
635kg/ha.
1016kg/ha.
2816kg/ha.

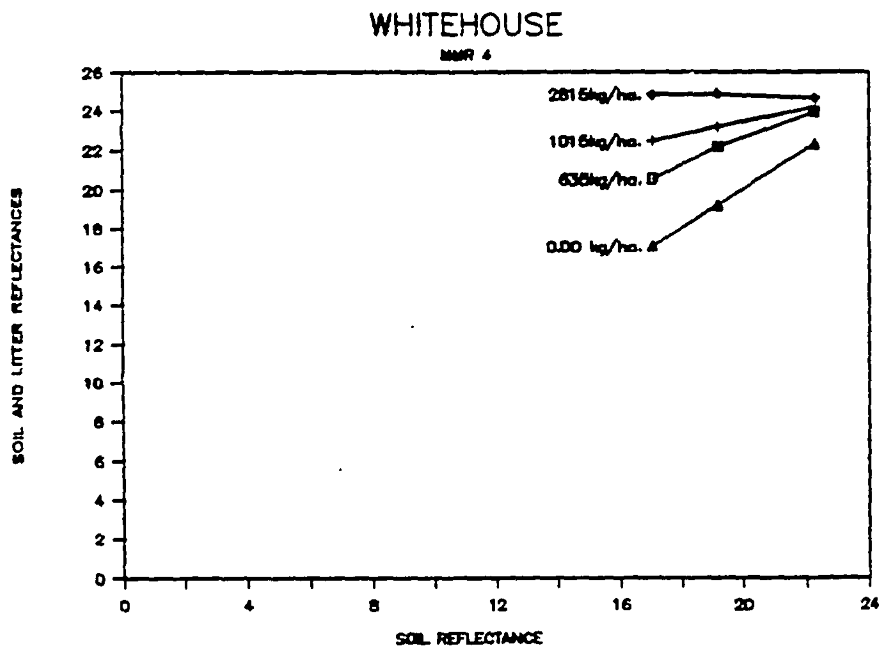

SUPERSTITION
0.00 kg/ha.
635kg/ha.
1016kg/ha.
2816kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
0
10
20
30
40
50
60

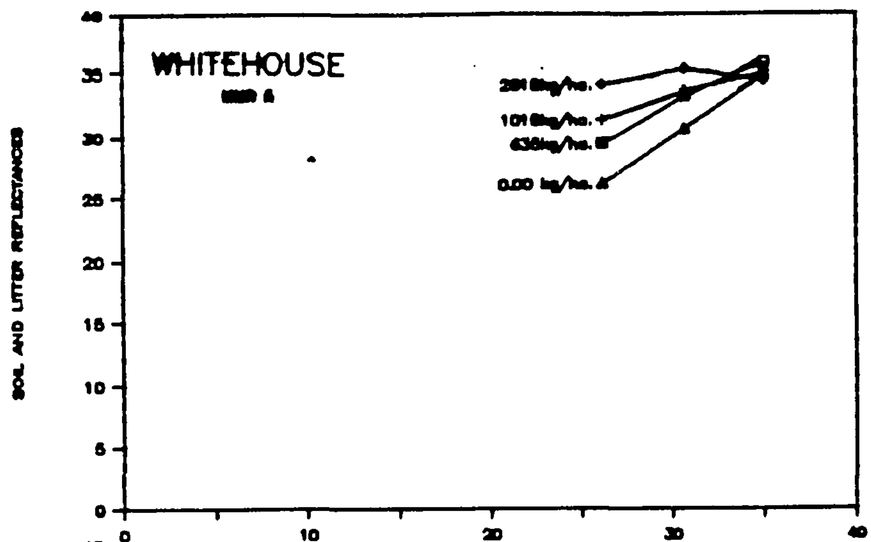

SUPERSTITION
0.00 kg/ha.
635kg/ha.
1016kg/ha.
2816kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
0
10
20
30
40
50
60

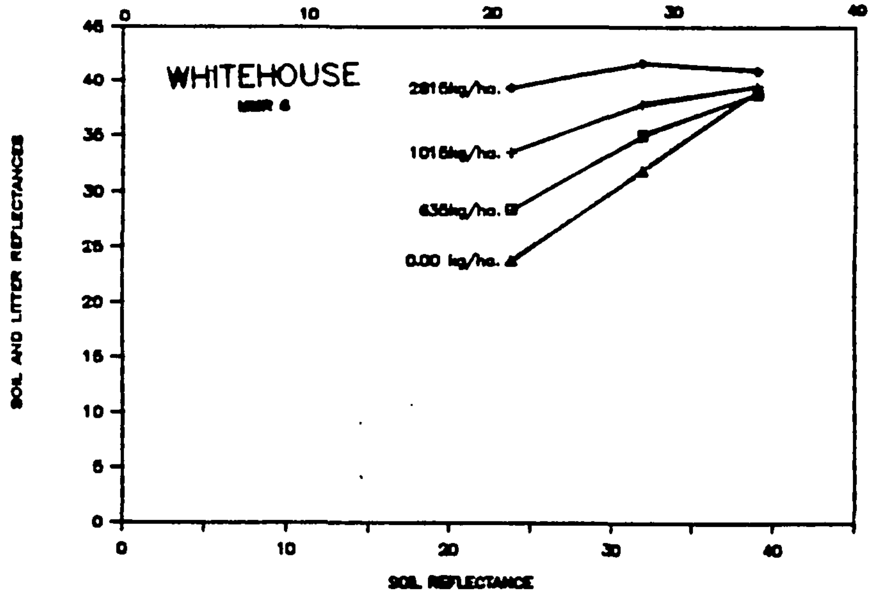

WHITEHOUSE
MMR 1
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.


WHITEHOUSE
MMR 2
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE
2815kg/ha.
1015kg/ha.
635kg/ha.
0.00 kg/ha.


WHITEHOUSE
MMR 3
281.6kg/ha.
101.6kg/ha.
63.6kg/ha.
0.00 kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE


WHITEHOUSE
MMR 4
281.6kg/ha.
101.6kg/ha.
63.6kg/ha.
0.00 kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE


WHITEHOUSE
2816kg/ha.
1016kg/ha.
636kg/ha.
0.00 kg/ha.
SOIL AND LITTER REFLECTANCES


WHITEHOUSE
2816kg/ha.
1016kg/ha.
636kg/ha.
0.00 kg/ha.
SOIL AND LITTER REFLECTANCES
SOIL REFLECTANCE

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