Type of Report: Semi-Annual, July - December 1992.
Alfredo R. Huete, University of Arizona
NAS5-31364

## TASK OBJECTIVES

The overall objective of the second half of this years' effort was to further analyze and evaluate vegetation indices for the MODIS product. Emphasis was placed on establishing criteria for evaluation of the multitude of vegetation indices being proposed for MODIS use. Currently the normalized difference vegetation index (NDVI), soil-adjusted vegetation index (SAVI), global environment monitoring index (GEMI), atmosphere-resistant vegetation index (ARVI), soil-atmosphere resistant vegetation index (SARVI), perpendicular vegetation index (PVI), and weighted difference vegetation index (WDVI) are being investigated with respect to sensitivity and _noise' related problems. The issue of functionality and whether one or more indices are needed is being considered. The role of the level 3, composited vegetation index product in the land cover algorithms was also considered.

## WORK ACCOMPLISHED

During the second half of this year, vegetation index studies continued to be focussed on semi-arid landscapes over Niger and Walnut Gulch, Arizona. The sparsity of vegetation over these landscapes enables one to test the vegetation index algorithms under the harshest conditions of a weak vegetation signal amidst a highly variable and dominant soil background. Since these areas are very sensitive to climatic fluctuations, an accurate determination of green vegetation becomes crucial. At both Arizona and Niger sites, multitemporal - vegetation index profiles were investigated with ground-based, aircraft, and satellite studies under various view-sun geometries, canopy backgrounds, and atmosphere conditions. This was accompanied by ground physical measurements of the plant-soil canopy such as leaf area index (LAI), green and yellow biomass, %cover, absorbed photosynthetically active radiation (APAR), seasonal production, and soil moisture and texture.

### 1. NIGER-HAPEX ACTIVITIES:

ASAS flights onboard the C-130 were carried out during the 8-week Special Observation Period (SOP), August 17 to October 9. The ASAS flights covered the grassland, grass-shrub mixture, millet, and degraded shrubland sub-sites within the 3 major supersites. A string of observations were made along the principal plane and at a $45^0$ diagonal. The ground campaign involved bidirectional reflectance factor (BRF) measurements with an SE 590 spectroradiometer, CCD red and near-infrared digital cameras, yoke-exotech radiometer transects, low level exotech radiometer airplane transects, ground biomass clippings, LAI, %cover, and APAR measurements. The objectives were to analyze anisotropic VI behavior, model the angular- vegetation index behavior of each of the sites, and functionally relate the vegetation index to biophysical plant parameters.

The Arizona contingency to the HAPEX-Niger effort was present for a 5-month period with the additional objective of analyzing vegetation-optical dynamics from _green-up' through the peak of the growing season and into the dry down, senesced period. Three graduate students (Kedra Segler, Wim van Leeuwen and Michael Guilbault) left for Niger for the summer period (June-October) to carry out both optical and biophysical characterization of several Sahelian cover types. The ground data has not been analyzed yet and the aircraft and satellite imagery have not yet been made available. However, the results of last summer's Niger activities 1991) have been completed and is presented in a manuscript entitled _Optical dynamics and vegetation index sensitivity to biomass and plant cover in arid shrub savannnah sites in Niger" by W.J.D. van Leeuwen, A.R. Huete, J. Duncan, and J. Franklin, for submission to Agriculture and Forest Meteorology.

## 2. WALNUT GULCH ACTIVITIES:

A full-time Research Specialist was hired in August to process the ASAS imagery obtained over the Walnut Gulch site during the dry season (August 1) and wet season (September 15) ASAS campaigns of 1991. The 29 band, 7 view angle ASAS images are being reduced into the MODIS bands using PCI and S-plus software on the Silicon Graphics workstation. The ASAS sites involve 4 key subsites within the Walnut Gulch Watershed, including the Kendall (grassland), Lucky Hills (shrubland), Gleeson (grass-shrub), and San Pedro (riparian, mesquite bosque) sites. A portion of this data, involving the Kendall site, was used in a paper presented at the _Soils and Vegetation Remote Sensing" workshop held in Tempe, Arizona, January 6-8, 1993. Some of the key results are presented below in the Data /Interpretation section of this report.

The objectives of this ASAS data analyses include: (1) perform MODIS simulation work from the ASAS imagery; (2) analyze the off-nadir images for possible multi-temporal compositing development of MODIS satellite acquisitions; (3) extract the bidirectional vegetation signal, free from the influence of the soil background; and (4) investigate the use of the 29 bands for mixture models of vegetation and soil-related studies whereby component signals are extracted from the composite canopy signal.

As a result of an EOSAT grant awarded to Dr. Susan Moran (USDA-ARS), we were provided with Landsat TM 5 satellite data from April through November, 1992. This multi-temporal data set was complimented with optical depth - atmospheric measurements and ground-truth yoke-based transects with an 8-band radiometer (MMR). Table 1 summarizes the full TM scenes acquired over Walnut Gulch in 1992. The MODLAND group has shown an interest in utilizing this data set for multitemporal MODIS-band simulation for land cover product development.

Table 1. Landsat TM 5 acquisitions over Walnut Gulch, Arizona in 1992.

| DATE | DOY | WEATHER | LANDSAT 5 |
|---|---|---|---|
| 23 April | 114 | marginal | yes |
| 9 May | 130 | clear | yes |
| 25 May | 146 | cloudy | no |
| 10 June | 162 | clear | yes |
| 26 June | 178 | clear | yes |
| 12 July | 194 | good | yes |
| 28 July | 210 | cloudy | no |
| 13 August | 226 | marginal | yes |
| 29 August | 242 | cloudy | no |
| 14 September | 258 | cloudy | no |
| 30 September | 274 | clear | yes |
| 16 October | 290 | clear | yes |
| 1 November | 306 | clear | yes |
| 17 November | 322 | clear | yes |

## 3. AVHRR STUDY SITES:

We are continuing work on a project utilizing part of an AVHRR data set involving 57 test sites extracted and compiled by the EDC from 1989-1992. This daily 20x20 km data windows includes all 5 channels as well as angular (sun and view) data and NDVI. The data are being composited into 14 day periods using various vegetation indices to eliminate cloud contamination, reduce atmospheric effects, and study the effects of surface anisotropy on the compositing methodology. The indices used include the NDVI, SAVI, GEMI, PVI, and the weighted difference vegetation index (WDVI). Other objectives include; to compare _length of growing season", _peak of growing season", and _initial green-up" variations due to vegetation index used and; to compare vegetation sensitivity to the composited products. A paper on this will be presented at the PECORA 12 Symposium on _Land Information from Space-based Systems" sponsored by EROS Data Center on August 24-26, 1993, in Sioux Falls, South Dakota.

## 4. CHINA TEST SITE SELECTION

Eleven potential test sites have been suggested and proposed by the LREIS, Institute of Geography of the Chinese Academy of Sciences for possible MODIS work (Table 2). There are 3 _key' ecological sites

(Changbai Mountain, Xilingoler grassland, and Maowusu shrubland sites; #1,10 &11) which are located along a landscape gradient of temperate forest - steppe - desert in the northern part of China. The first two are key sites in the Ecological Network of the Chinese Academy of Sciences, and the third site is an experimental site supported by the Chinese National Science Foundation. All 3 sites have extensive ground measurement studies and are part of the Chinese National Global Change Programme.

The Changbai site is temperate, mixed conifer with decidous broadleaf forest, with an area of $8000 km^2$ and continental climate with monsoon activity. The site is 13 years old. The Xilingoler site is representative of temperate steppe with an area of $200{,}000\ km^2$. The climate is temperate, semiarid continental with an elevation of 1000 m. This also was established 13 years ago. The Maowusu site is in a transition zone involving desert steppe and broadleaf forest and is composed of mainly shrub vegetation.

Table 2. The current list of potential China Sites to be considered for the MODLAND global test site network.

| Site # / Province | Location E-W | Location N-S | |
|---|---|---|---|
| 1. Changbai Mountain; Jilin | 127.9 | 42.0 | Northeast China (Ecology conserv. zone) |
| 2. Jinguangshan Mt.; Jiangxi | 114.1 | 26.5 | Southeast China (Plant Conserv. zone) |
| 3. Zhangjiajie Mountain; Hunan | 111.3 | 28.7 | Middle China (National forest park) |
| 4. Hengshan Mountain; Hunan | 112.7 | 27.3 | Middle China (forest zone) |
| 5. Tinghushan; Guangdong | 112.6 | 23.4 | South China (Tropical forest park) |
| 6. Xishuangbanne; Yunnan | 102.3 | 24.5 | Southwest China (trop. forest natl. park) |
| 7. Gongjiashan; Xichuan | 101.9 | 29.7 | Mid-west China (forest) |
| 8. Jiuzhaigou; Xichuan | 104.5 | 30.5 | Mid-west China (forest) |
| 9. Shabaotou; Gengshu | 104.1 | 36.8 | Northwest China (desert) |
| 10. Xilingoler Grassland site | 116 | 44 | Central part of Xilingoler steppe |
| 11. Maowusu Shrubland site | 109 | 38 | |

## 5. SEMINARS, VISITS, AND MEETINGS

5.1. The MODLAND group had a thematic meeting at Flathead Lake, Montana from September 21 - 23 in order to specifically discuss approaches and research directions needed for the development of the Land Cover and Land Cover Change products. We discussed how the land cover products would be used in context of the USGCRP and Eos Payload Panel recommendations. The land cover product will have important applications in the climate and hydrology; biogeochemical cycles; and ecology and dynamics areas of the above programs.

The validation of the land cover product revolved around the use of test sites, chosen from a variety of locations to encompass a global network of sites. The 50 MSS scenes amassed by the EDC will be an initial starting point for this. The Landsat Pathfinder will also be utilized to further expand upon the test sites. Given these test sites, the MODLAND group will test and demonstrate how the land cover algorithms work over the different sites.

Since most of the MODLAND algorithm products will serve as input into the larger based land cover product, a cooperative research strategy is needed on the part of MODLAND members. As part of my obligation to this product, I will be exploring the use of spectral-temporal mixture modeling in component extraction both for the purpose of enhancing the _green vegetation signal as well as to develop new spectral features useful in land cover discrimination, such as _brightness' or _yellowness', etc. In a temporal sense, mixture modeling will aid in separating temporally-unique phenologic patterns, particularly if there are a multitude of plant species with varying phenologies present in a scene or within a pixel. I will also work with the development of the China test sites as well as in making the 1992 Walnut Gulch TM data available to the MODLAND team. This would have to be worked out with both EOSAT and Dixon Butler.

5.2 LTER-NASA workshop near Albuquerque, New Mexico; November 11-13 @ Sevilleta LTER site.

Chris Justice and myself attended this workshop which was aimed at bringing together NASA scientists with NSF scientists working in the LTER sites for future collaborative studies. My presentation to the group was entitled _Striving for a first-cut global classification of vegetation from seasonal variation in NIR and red reflectance index".

The LTER network of sites, is collectively an NSF center. There are currently 18 sites throughout the U.S., but 50 more domestic sites and 50 more international sites are desired by the year 2000. Currently, standardization of measurements and ground-based equipment among the sites is a high priority. NASA is currently supplying each of the sites with geocoded Landsat imagery ($800K) and in return the LTER group would verify classification schemes, confirm apparent changes in landscapes over the next 5 years, and provide a long-term ground data record.

A major conclusion of the workshop was to initiate collaborative

research programs involving NASA and LTER scientists. NASA would assist in supplying co-registered (AVHRR & Landsat) satellite data as well as airborne sensor data, ground radiometry, and sun photometer measurements over a small number of _focusses" cooperative projects.
One such collaborative example is to be prepared and presented for the _All Scientists Meeting" (NSF); Sept. 18-24, 1993, in Estes Park, CO. The MODIS land team will be represented at this meeting and will also encourage the LTER scientists to attend specific MODLAND thematic meetings in 1993. Examples of collaboration include; (1) joint funding of process studies; (2) scientists/ students exchanges in field and lab facilities; and (3) data management and information.

The MODIS land team is interested in looking at land cover/change with respect to the different biomes within the LTER network. We are also interested in the physical attributes of each biome which serve as input into various ecosystem and GCM models; the inherent spatial heterogeneity of each biome; and to develop a land cover logic driven by remote sensing and which can be verified and validated on the ground.

DATA/ ANALYSIS/ INTERPRETATION

## 1. SENSITIVITY STUDY OF VEGETATION INDICES

A manuscript entitled _Development of vegetation and soil indices for MODIS-EOS" was prepared by A. Huete, C. Justice, and H. Liu for submission to a special issue of Remote Sensing of Environment. This special issue is a result of the _Remote Sensing of Soils and Vegetation" workshop held in Tempe, Arizona Jan.6-8, 1993, and sponsored by the USDA-ARS in Phoenix, Arizona.

A good vegetation index (VI) not only must exhibit a high sensitivity to the _green' vegetation signal, but must also be insensitive to all _noise" factors, hence signal to noise ratio. The dynamic range of a VI represents the range of VI values from bare soil to full, dense canopy cover. The _noise' factor includes VI variations not attributed to a change in green vegetation and includes sensor calibartion; atmosphere-induced variations; view-sun angle variations in the VI; and canopy background causes in VI variations. Lastly, if the VI is used to extract LAI values then not knowing the plant canopy type, biome type, or species composition will reduce the accuracy with which LAI can be estimated since 2 different canopies with similar LAI will produce different VI values dependent mostly on the architecture of the canopies.

One measure of VI sensitivity or performance is the vegetation signal to noise ratio diagrammed in Figure 1. The signal to noise ratio (S/N) is computed at each level of vegetation cover (or biomass, LAI, etc.) in order to analyze the performance of VI's throughout the range of expected vegetation conditions occurring globally. Equation 1 defines the S/N as:

$$\text{signal / noise} = (VI_{canopy} - VI_{soil}) \;/\; (2*STD)_{canopy}, \qquad (1)$$

where the signal is defined as the difference in VI values for the canopy cover of interest and bare soil. The noise is defined as two times the standard deviation (2*STD) in VI variations occurring as a result of _noise' for the same vegetation cover. Thus, the signal would actually represent the mean VI values for the canopy of interest and bare soil. One may also translate the S/N ratio into the %uncertainty in predicting vegetation with equation 2:

$$\%\text{vegetation uncertainty} = (2*STD) \;/\; VI_{full} - VI_{soil}, \qquad (2)$$

where the denominator is the dynamic range of the VI from full canopy to bare soil.

Figures 2 - 5 are examples of these equations applied to several VI's using a ground-based data set whereby the different (temporal) levels of cotton cover were measured with 8 different soil backgrounds (4 soil types by 2 moisture levels) and two different, simulated atmospheres using the 5S code (10km and infinite visibilities). In Fig. 2 the S/N ratio is computed with only soil backgrounds varying for each level of green cover. There is quite a large difference in S/N ratios with the NDVI performing the worst at less than 60% green cover and the SAVI (and MSAVI) performing the best. At beyond 75% green cover, the soil noise becomes minute with canopy closure and hence the S/N ratios approach infinity. In Fig. 3, the %vegetation uncertainties are shown with the NDVI and ARVI showing a 20-30% level of uncertainty at low to medium green covers while the SAVI and PVI had 5% uncertainty levels.

Figure 4 shows the same S/N ratios but with both soils and atmosphere varying. At low to medium green covers, the SAVI had the best S/N followed by the GEMI and NDVI while at medium to high green covers the SARVI stood out as the best VI. Unfortunately, the SARVI behaved poorly at lower amounts of green cover. The overall % uncertainty shows the ARVI and NDVI to be very unreliable in predicting green covers while the SAVI was very reliable from 0-50% green cover and the SARVI from 50-100% green cover (Fig. 4b).

These results show that there are wide differences in VI performance using different VI's and at different levels of vegetation density. The selection of an _optimum' index is not as straightforward and is partially depedent on the extent to which atmosphere correction algorithms become operable.

## 2. ASAS RESULTS OVER WALNUT GULCH

A second data set of interest in evaluating VI's is the ASAS data collected over the Kendall semi-arid grassland area within the Walnut Gulch Experimental Watershed. The grassland site is fairly uniform, consisting of grama grasses over a slighly rolling landscape of north and south facing slopes (<5% slopes). The ASAS data was reduced into the MODIS bands for computation of VI's. The multi-angular VI results show the NDVI to be topographically sensitive in that the north facing slopes have higher NDVI values than the south facing sites (Fig. 5). By contrast, the SAVI and WDVI show little topographic effects. This can be seen quite clearly in the VI images (Fig. 6). In Fig. 7, we compare a dense grass site within the Kendall area with the tree values extracted along the washes. The WDVI shows the dense grass area to have the same value as the trees and thus cannot distinguish between the two. The SAVI shows the dense grass area to have values greater than the sparser grass but less than the trees, while the NDVI shows the dense grass values to be the same as the sparser grass on north slopes. Thus, the VI's show considerable discrepancy in the interpretation of 4 vegetation conditions: (1) north sparse grass; (2) south sparse grass; (3) dense grass; and (4) trees.

This forces the issue of functionality. Are all VI's more or less correlated? or do some extract unique information from the canopy and hence should MODIS be developing a single index or multiple indices. In figure 8 we plot the SAVI vs. the NDVI for the ASAS data set and compare with the red-NIR reflectances for the same data. The VI scatterplot shows more variation and hence each index is displaying different information about the grass canopy.

## ANTICIPATED FUTURE ACTION

### 1. SCAR EXPERIMENT

A proposal entitled _Smoke Clouds and Radiation (SCAR) experiment" was prepared and submitted with Y. Kaufman as principal investigator and M. King, C. Justice, D. Tanre, A. Huete, and others as co-investigators. The primary aim of the project is to study biomass burning in the tropics and how the release of trace gases affects atmospheric chemistry and climate. In addition, remote sensing information of the earth's surface and atmosphere will generate data for the evaluation and validation of MODIS algorithm products. Simultaneous measurements of the physical and chemical components of the earth's surface and atmosphere will be made in order to investigate the effect of biomass burning on surface vegetation properties and their regrowth. The MODIS land group will use the data to contribute to the development and validation of the algorithms for MODIS land leaving radiance, fire size and temperature, land cover and vegetation indices.

The experiment will be accomplished in two phases:

1. Phase 1 - 1993: Eastern US - SCAR

A preliminary experiment will be conducted during 2 weeks in June-July 1993 in the Eastern US. The purpose of this experiment will be to test the logistics of the SCAR measurements, and to start the collaboration between the international participants in SCAR. The experiment will include ER-2 flights, the MODIS simulator (MAS), a lidar system, and AVIRIS. Ground-based measurements with sunphotometers will also be made.

2. Phase 222 - 1994: Brazil - SCAR

The main SCAR experiment will be conducted during 4 weeks in August-Sept. 1994 in Brazil. The experiment will include ER-2 and MAS flights with lidar and flux radiometers along with ground-based measurements of vegetation and atmosphere properties. Sites with different vegetation properties and burning conditions will be chosen and satellite imagery (AVHRR and LANDSAT-TM) will be collected to correspond with the aircraft measurements at these sites.

## 2. BOREAS

A BOREAS proposal on behalf of the MODLAND team was submitted by Steve Running. As of yet there is no new developments on this project but this will involve a similar effort as HAPEX-Sahel. Here we will be able to start investigating MODLAND products over more densely vegetated canopy types within the Boreal forests. Areas to be studied include burned areas, secondary growth, open wetland areas, snow ground cover conditions, ash/charcoal backgrounds, regrowth areas, and seasonality.

## 3. IGARSS'93 CONFERENCE

An abstract has been submitted to present a paper at the IGARSS'93 conference to be held at Kogakuin University, Tokyo, Japan on August 18-21, 1993. The abstract is attached and is entitled _Extraction of soil and vegetation parameters from bi-directional ASAS imagery".


**ABSTRACT**

High spectral resolution reflectance spectra were collected during the dry and wet seasons of the Walnut Gulch Experimental Watershed, Arizona with the Advanced Solid-State Array Spectroradiometer (ASAS) onboard the NASA C-130 aircraft. The 29-band images (447 - 883nm) were collected over 7 viewing angles along the solar principal plane as well as in 7 angles orthogonal to the solar plane. A spectral mixture model was applied to the multi-angle, multispectral data set in order to separate and extract the green vegetation, senesced vegetation, and soil components. As expected the _loadings' of each component varied with viewing angle in accordance with canopy structure and sun position. Off-nadir viewing resulted in the highest vegetation loadings, independent of view azimuthal orientation, including along the principal plane. The sensitivity of the extracted vegetation signals over the various viewing geometries were then compared with various vegetation indices derived from ASAS simulated MODIS bands. The mixture model results were found to be more sensitive to green vegetation than the vegetation indices, a result of the more efficient use of spectral wavelengths and viewing geometries for detection of the vegetation signal.


## 4. PECORA 12 SYMPOSIUM

We are continuing analyzing the EDC multitemporal, vegetation index compositing project with the AVHRR test site areas. Some preliminary results are to be presented at the PECORA 12 Symposium on _Land

Information from Space-based Systems” sponsored by EROS Data Center on August 24-26, 1993, in Sioux Falls, South Dakota.

## PROBLEMS/ CORRECTIVE ACTIONS

The MODIS product flow diagram has the vegetation index product as input to the atmosphere product algorithms. Areas with high VI values are assumed to be _dark’ in the visible, thus providing a scheme for path radiance determination. A change was requested to place the atmosphere correction algorithms as input to the VI product so that surface reflectances rather than _apparent” reflectances be used in derivation of the VI product. The solution appears to be to have an iterative procedure whereby the VI is first computed from apparent reflectances and then from surface reflectances once the atmosphere product is derived.

To what extent will the atmosphere correction scheme be operable and implemented remains unclear. Thus the VI product could be derived from any intermediate condition between that of _apparent” reflectances (no correction) to that of surface reflectances (full correction). It may be that only an ozone correction or water vapor correction is implemented leaving aerosols unaccounted for. Regardless, the uncertainties present in the none, partial, or fully corrected atmosphere product would have to be passed along and included in the overall uncertainty of the VI algorithm.

One solution is to evaluate all the VI products under the whole range of atmospheric conditions mentioned above with the goal of finding a VI algorithm least affected to the extent of atmosphere correction. This approach would favor the selection of self-atmosphere correcting VI’s such as the GEMI, ARVI, and SARVI. If, on the other hand, separate indices performed best under different atmospheric correction scenarios then the VI selection process would be compromised.

## PUBLICATIONS

Huete, Justice, and Liu, 1993, Development of vegetation and soil indices for MODIS-EOS, for submission to Remote Sensing of Environment.

van Leeuwen, W.J.D., Huete, A.R., Duncan, J., and Franklin, J., 1993, Optical dynamics and vegetation index sensitivity to biomass and plant cover in arid shrub savannnah sites in Niger, for submission to Agriculture and

Forest Meteorology.

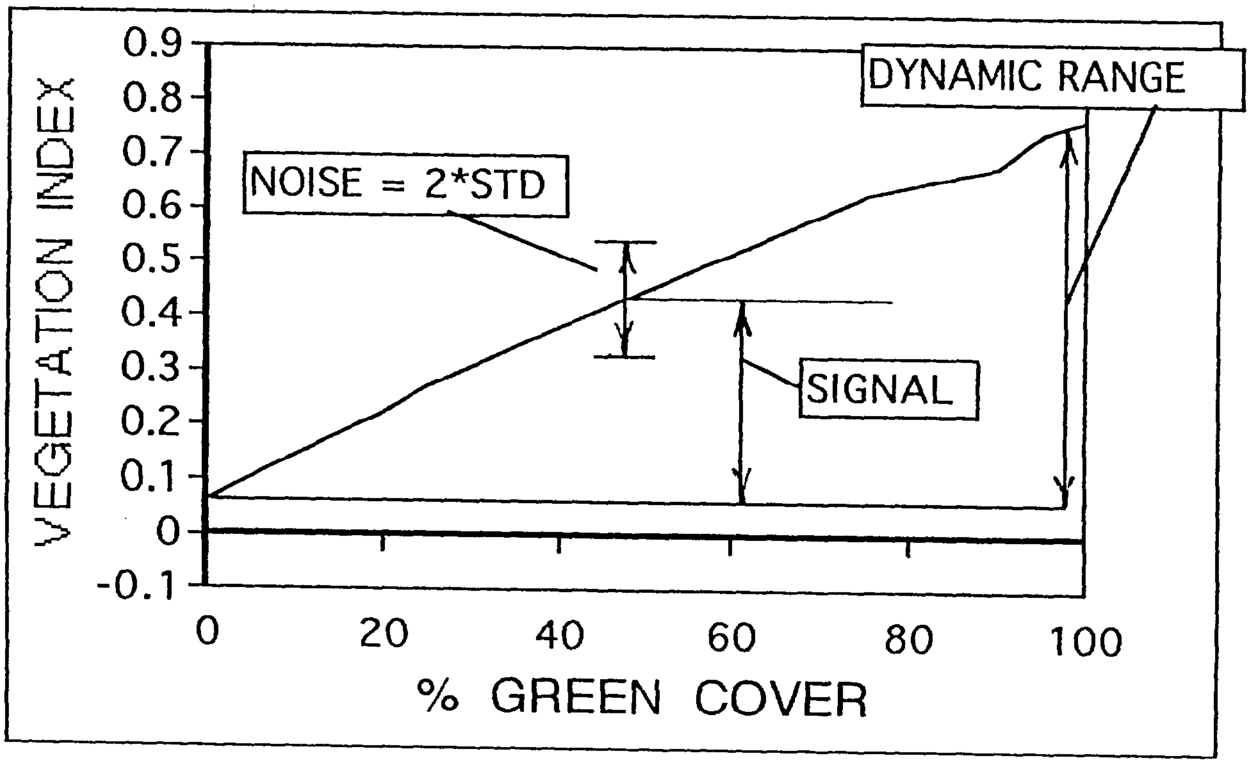
Qi, J., , Chehbouni, A., Huete, A.R., Kerr, Y.H., A modified soil adjusted vegetation index: MSAVI, for submission to Remote Sensing of Environment.

Huete, A.R., Hua, G., Qi, J., Chehbouni, A., and Leeuwen, van W.J.D., 1992, Normalization of multidirectional red and NIR reflectances with the SAVI, Remote Sens. Environ. 41:143-154.

Abstract

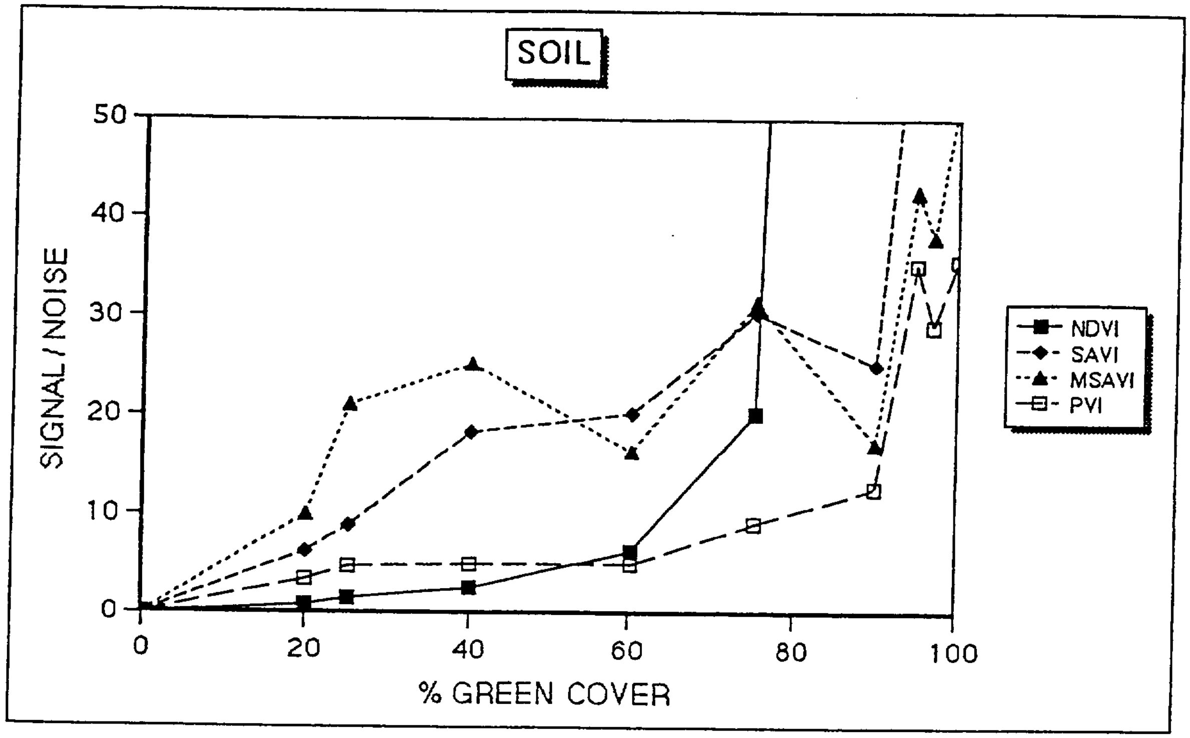
_Development of vegetation and soil indices for MODIS-EOS" was prepared by A. Huete, C. Justice, and H. Liu; _Remote Sensing of Soils and Vegetation" workshop held in Tempe, Arizona Jan.6-8, 1993, and sponsored by the USDA-ARS in Phoenix, Arizona. p. 16.

FIGURE 1. Signal to noise ratio concept in the evaluation of vegetation indices.




$$SIGNAL/\ NOISE = (VI_C - VI_S)\ /\ (2^*\ STD)_C$$

$$\%\ VEGETATION\ UNCERTAINTY = (2^*\ STD)_C\ /\ VI_{100\%} - VI_S$$



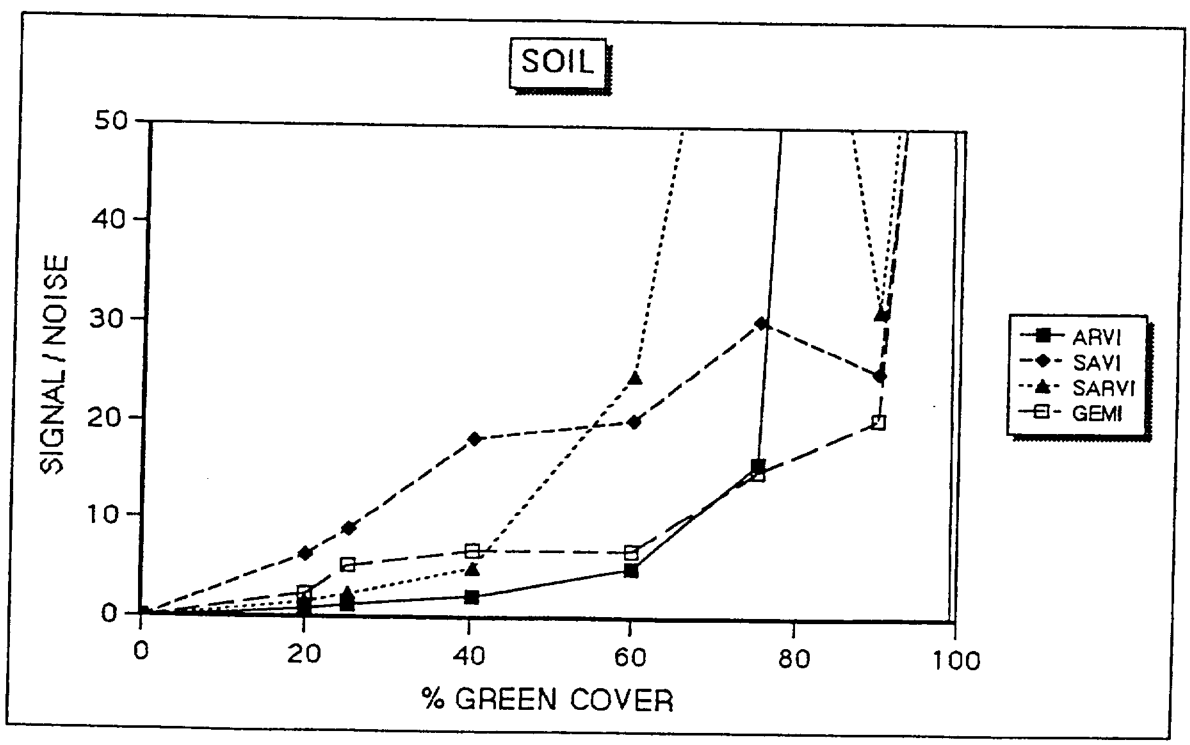




Figure 2. Signal to noise ratios computed for several VI's in which the soil background is the primary noise factor.

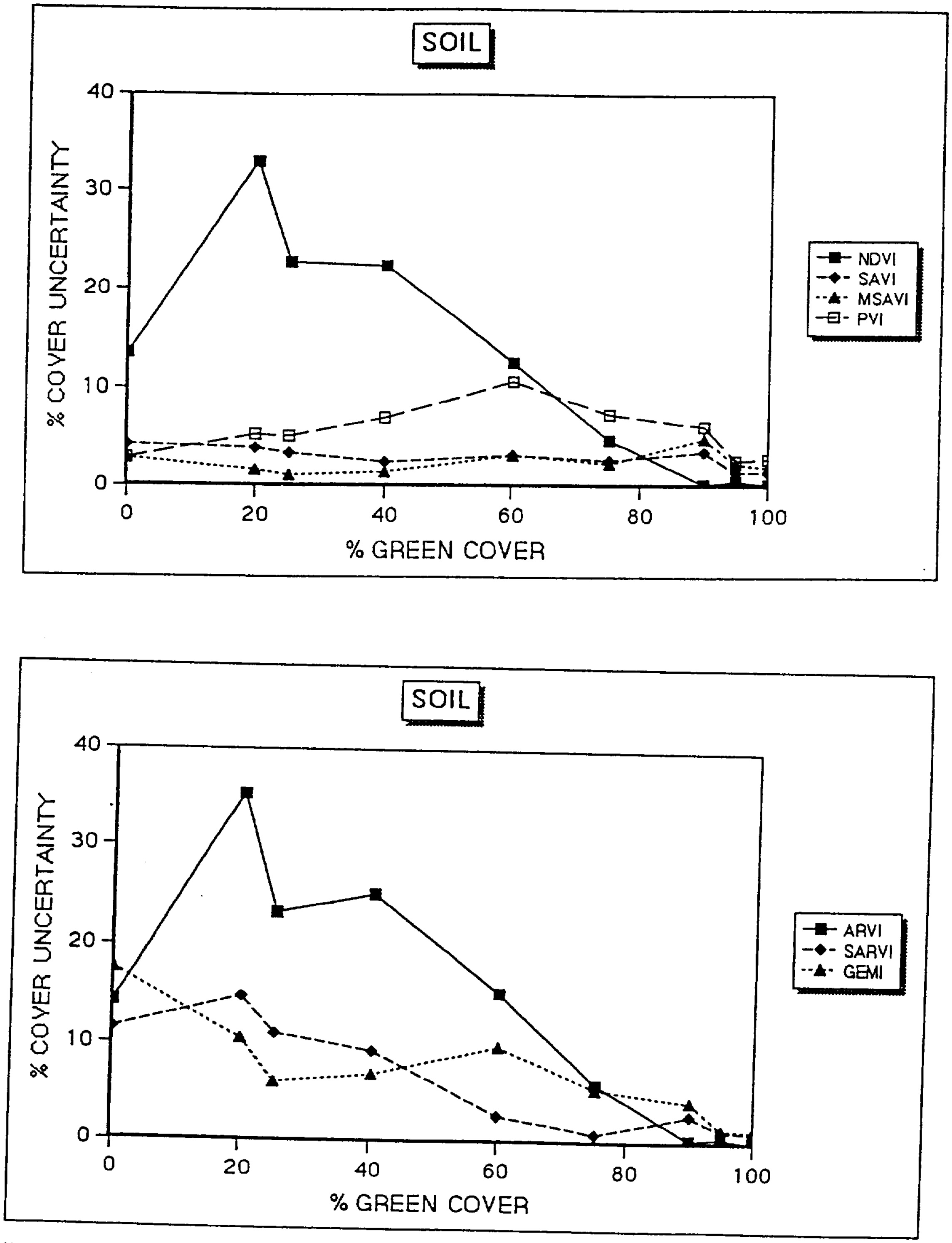



Figure 3. Percent green cover uncertainties in predicting vegetation from the VI in which the soil background is the primary noise factor.

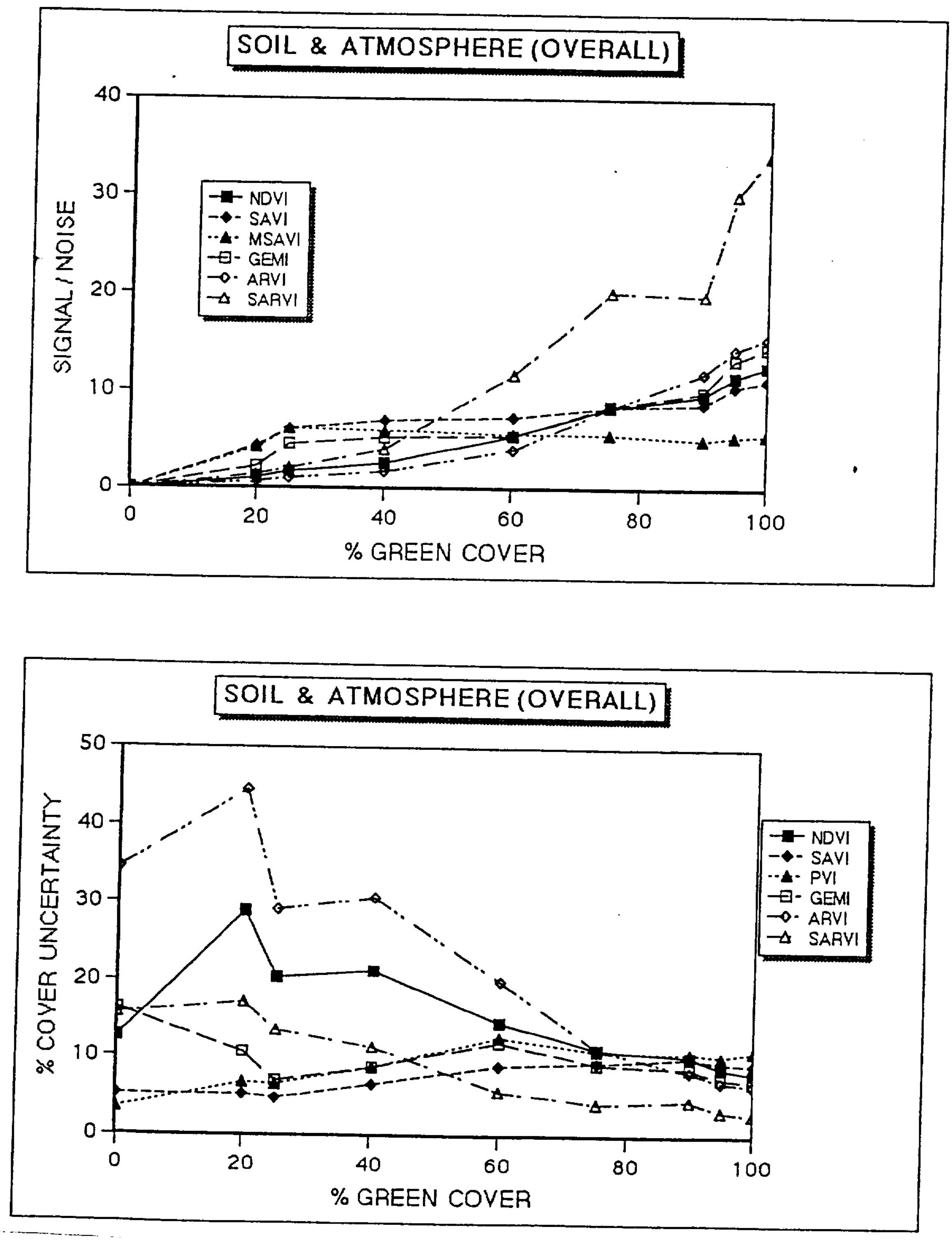



Figure 4. Signal to noise ratios (a) and percent green cover uncertainties (b) in predicting vegetation computed for several VI's in which both the atmosphere and soil background contribute to the noise.

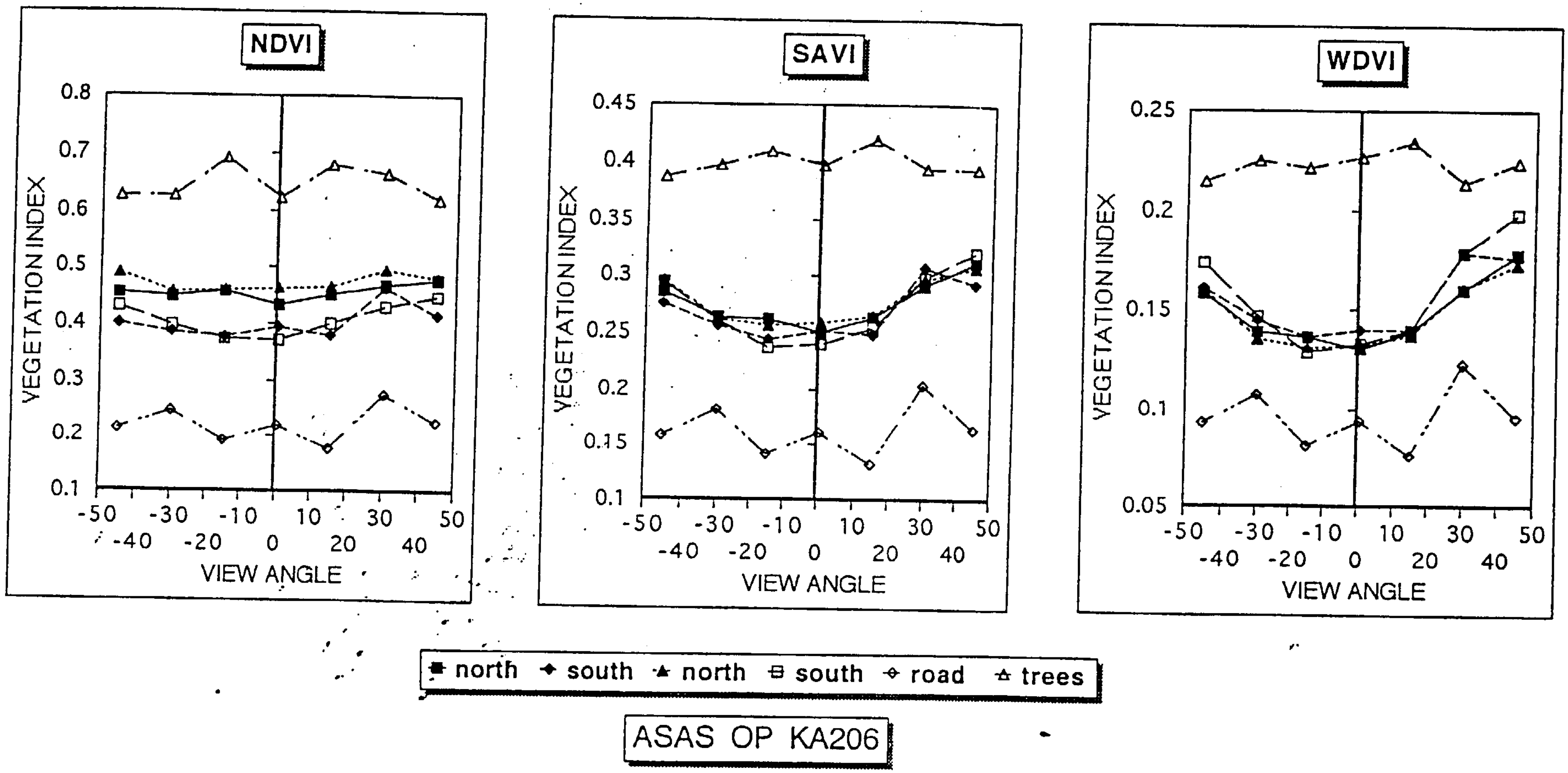



Figure 5. ASAS derived VI results for Kendall grassland site along the orthogonal plane to the sun.

Figure 6. ASAS VI imagery of the NDVI (a), SAVI (b), and 3-band composite (c) for Kendall grassland site at nadir view (#1 is south facing slope; #2 is north facing slope; #3 is dense grass area; #4 is trees; and #5 is the road).

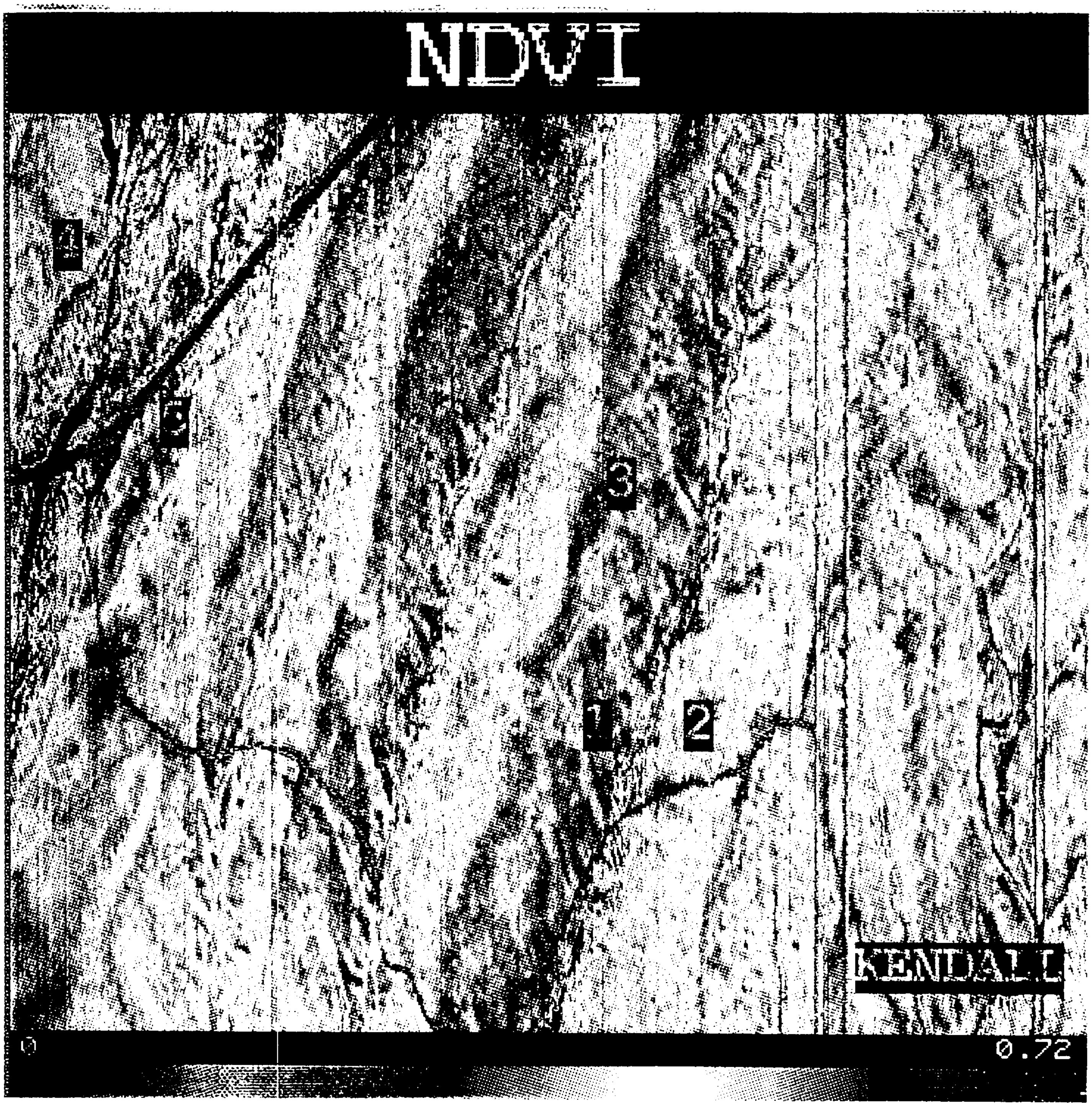
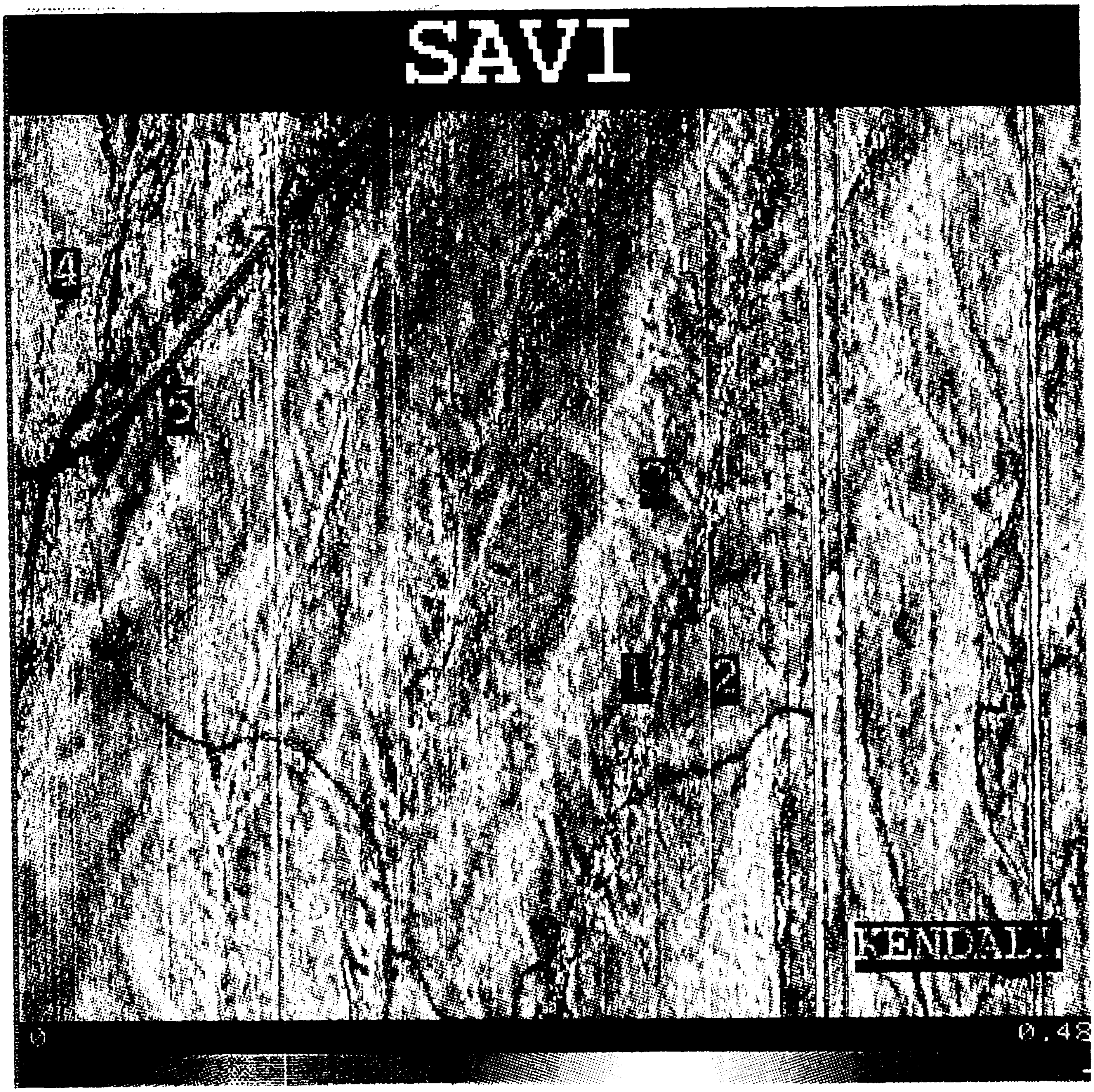
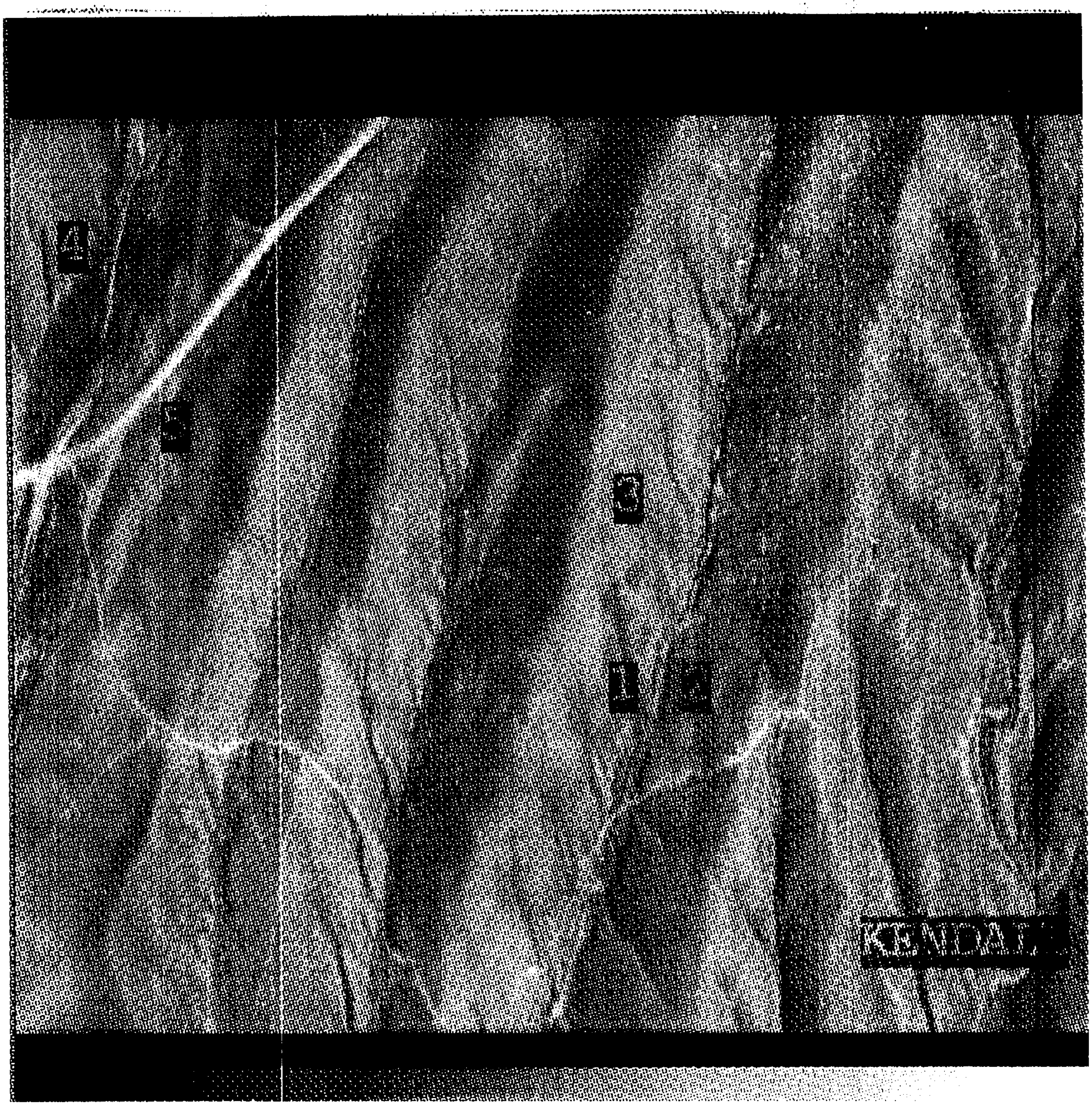


Figure 6. ASAS VI imagery of the NDVI (a), SAVI (b), and 3-band composite (c) for Kendall grassland site at nadir view (#1 is south facing slope; #2 is north facing slope; #3 is dense grass area; #4 is trees; and #5 is the road).




KENDAL

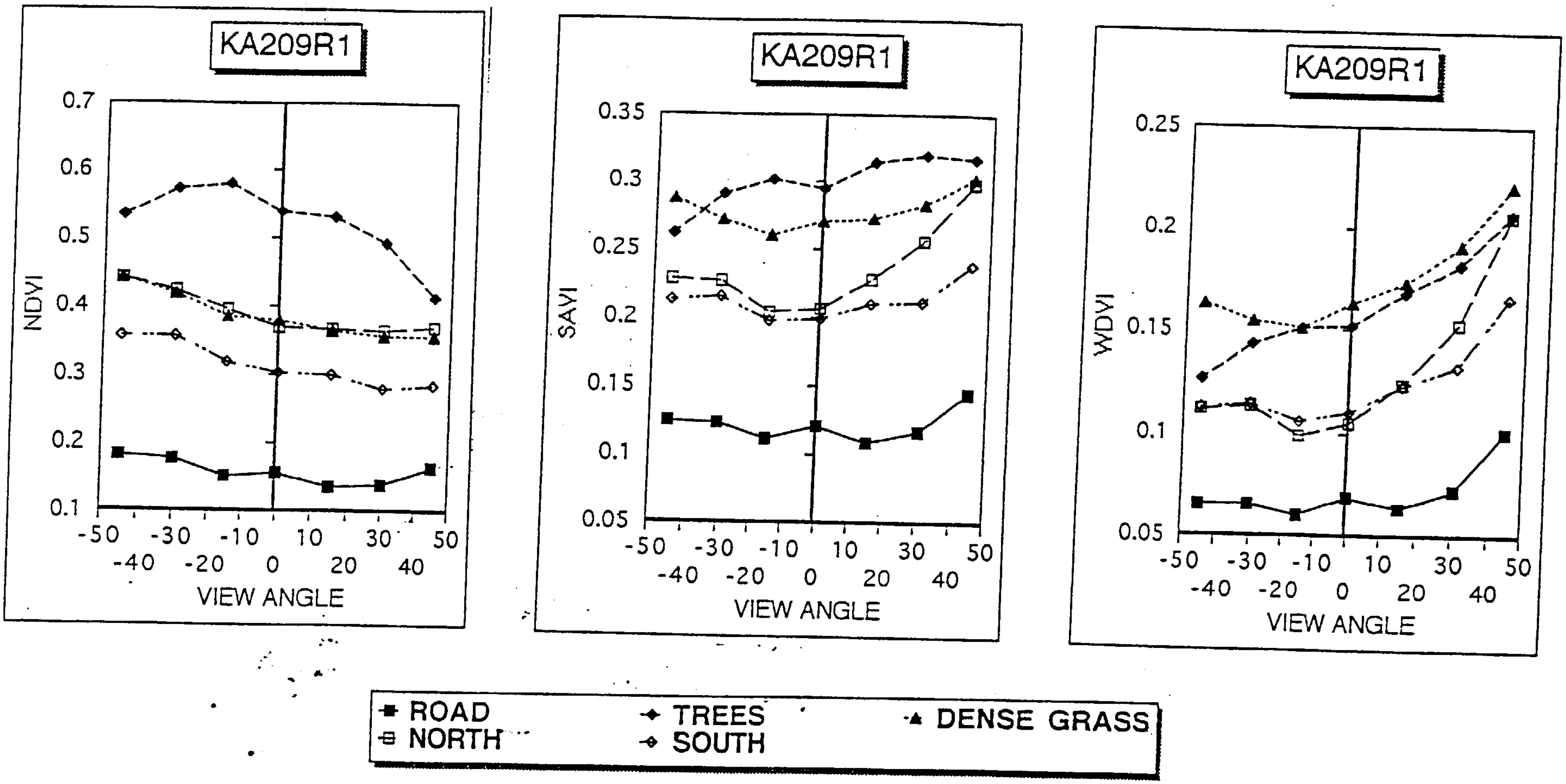



Figure 7. ASAS derived VI results for Kendall grassland site along the principal plane to the sun.

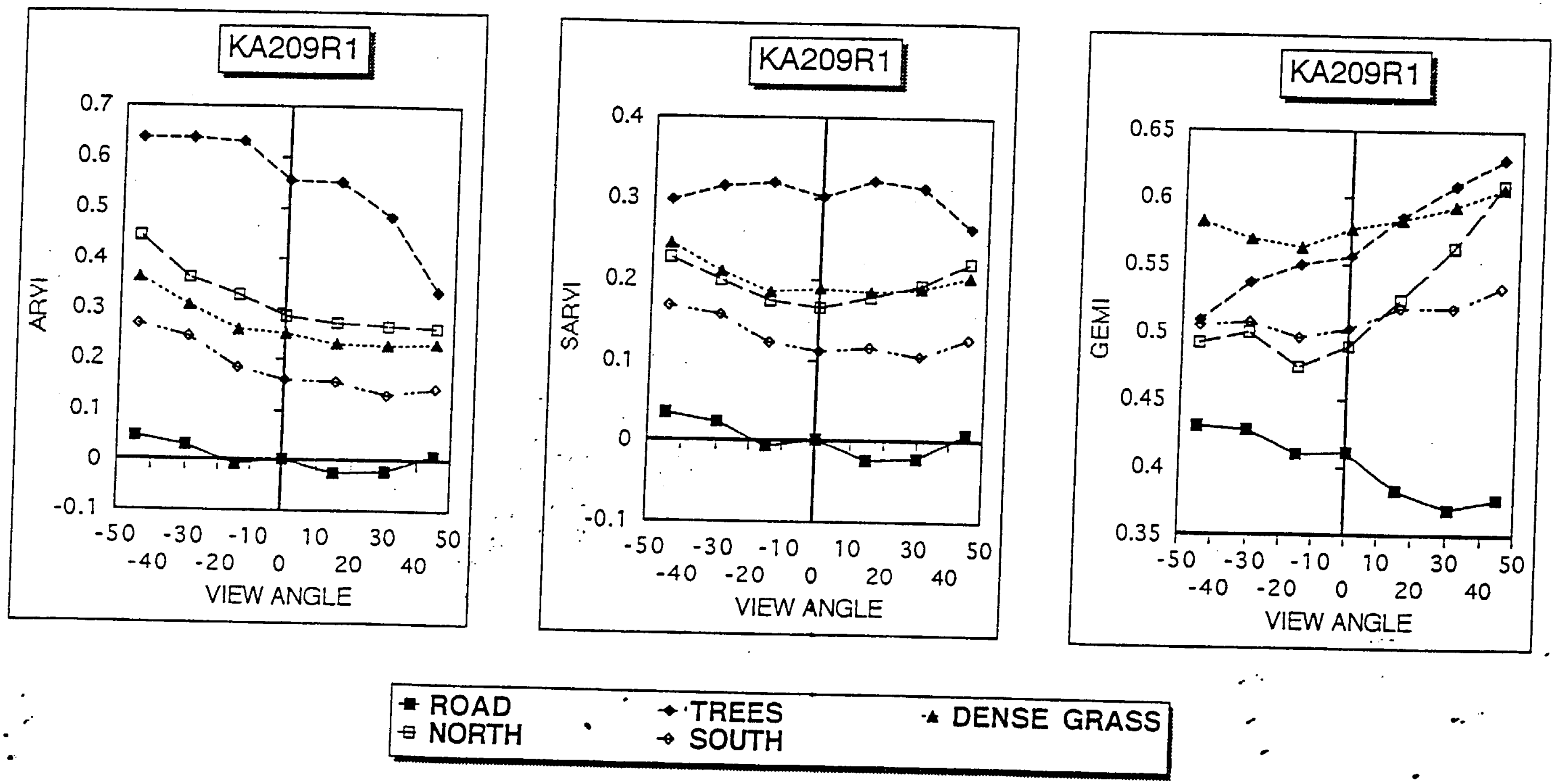



Figure 7. ASAS derived VI results for Kendall grassland site along the principal plane to the sun.

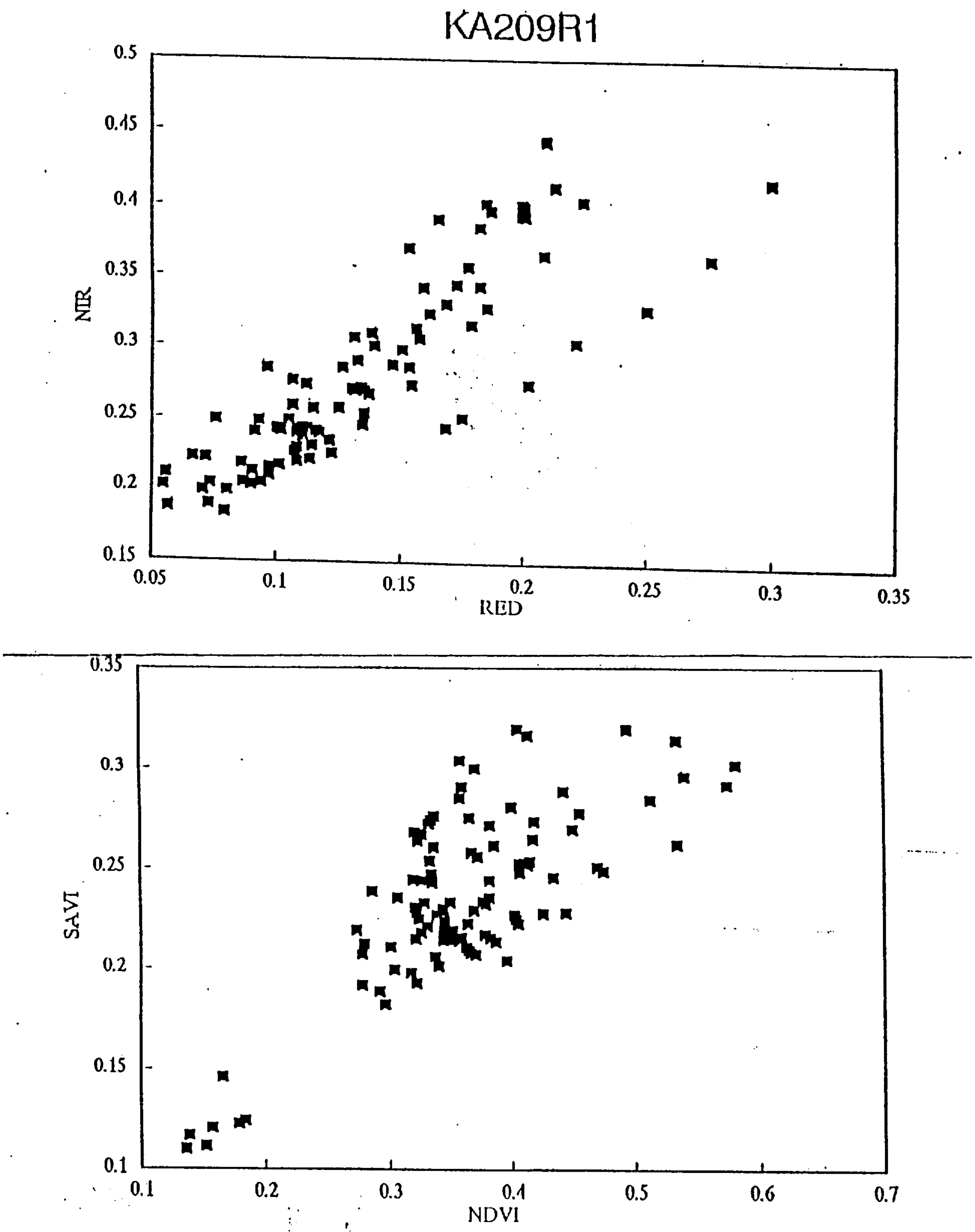



Figure 8. Red and NIR crossplots (a); and SAVI vs. NDVI crossplots for ASAS results at Kendall grassland site.