## General Disclaimer

## One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

RECEIVED BY
NASA STI FACILITY
DATE: 11-21-78
DCAF NO. 002949
PROCESSED BY
☒ NASA STI FACILITY
☐ ESA - SDS ☐ AIAA

(NASA-CR-157803) SEPARABILITY OF AGRICULTURAL COVER TYPES IN SPECTRAL CHANNELS AND WAVELENGTH REGIONS (Instituto de Pesquisas Espaciais, Sao Jose) 21 p HC A02/MF A01 CSCL 02C G3/43

N79-11451

Unclas 37665

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLOGICO
INPE
INSTITUTO DE PESQUISAS ESPACIAIS

| | | |
|---|---|---|
| 1.Classification *INPE-COM.10/PE* *CDU. 621.38SR:631* | 2.Period | 4.Distribution Criterion<br>internal [ ]<br>external [X] |
| 3.Key Words (selected by the author)<br>*SEPARABILITY OF AGRICULTURAL CROPS, WAVELENGTH BAND SELECTION, SPECTRAL CHANNELS FOR FUTURE SATELLITES, SPECTRAL CHANNEL EVALUATION, WAVELENGTH REGION EVALUATION.* | | |
| 5.Report No. *INPE-1147-PE/100* | 6.Date *October, 1977* | 7.Revised by *C. R. Souza*<br>*Celso de Renna e Souza* |
| 8. Title and Sub-title<br>*SEPARABILITY OF AGRICULTURAL COVER TYPES IN SPECTRAL CHANNELS AND WAVELENGTH REGIONS* | | 9.Authorized by<br>*Parada*<br>*Nelson de Jesus Parada*<br>*Director* |
| 10.Sector *DSE* | Code | 11.No. of Copies *11* |
| 12.Authorship *Ravindra Kumar* | | 14.No. of Pages *21* |
| 13.Signature of first author *Ravindra Kumar* | | 15.Price |

16.Summary/Notes

*The purpose of this study was to evaluate the spectral channels as well as wavelength regions - visible, near infrared, middle infrared and thermal infrared - with respect to their estimated probability of correct classification ($P_c$) in discriminating agricultural cover types. Multispectral scanner data in twelve spectral channels in the wavelength range of 0.4 to 11.7 μm acquired in the middle of July for three flightlines were analysed by applying automatic pattern recognition techniques. The same analysis was performed for the data acquired in the middle of August, 1971, over the same three flightlines, to investigate the effect of time on the results. The effect of deletion of each spectral channel as well as each wavelength region on $P_c$ is given. Values of $P_c$ for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels are also given. The overall values of $P_c$ were found to be greater for the data of the middle of August than the data of the middle of July.*

17.Remarks *Submitted to IEEE Transactions to consider for publication.*

LIST OF TABLES

TABLE I Wavelength Bands of the Spectral Channels

TABLE II Effect of Deletion of Each Channel on the Percentage Probability of Correct Classification

TABLE III Effect of Deletion of Each Wavelength Region on the Percentage Probability of Correct Classification

TABLE IV Evaluation of Combinations of Wavelength Regions

# SEPARABILITY OF AGRICULTURAL COVER TYPES IN SPECTRAL CHANNELS AND WAVELENGTH REGIONS

R. Kumar

## ABSTRACT

The purpose of this study was to evaluate the spectral channels as well as wavelength regions - visible, near infrared, middle infrared and thermal infrared - with respect to their estimated probability of correct classification ($P_c$) in discriminating agricultural cover types. Multispectral scanner data in twelve spectral channels in the wavelength range of 0.4 to 11. 7 μm acquired in the middle of July for three flightlines were analysed by applying automatic pattern recognition techniques. The same analysis was performed for the data acquired in the middle of August, 1971, over the same three flightlines, to investigate the effect of time on the results. The effect of deletion of each spectral channel as well as each wavelength region on $P_c$ is given. Values of $P_c$ for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels are also given. The overall values of $P_c$ were found to be greater for the data of the middle of August than the data of the middle of July.

## INTRODUCTION

The purpose of this study was to determine the statistical separability of multispectral measurements from agricultural cover types for evaluation of spectral channels as well as

---

*This work was supported by the Instituto de Pesquisas Espaciais (INPE/CNPq).*
*The author is with the Instituto de Pesquisas Espaciais (INPE), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), 12.200 S. J. dos Campos, S. Paulo, Brasil.*

wavelength regions -- visible, near infrared, middle infrared and thermal infrared. The data were analysed in subsets of one to twelve spectral channels, in the wavelength range 0.46 to 11.7 μm for selected flightlines of the 1971 Corn Blight Watch Experiment[1]. The agricultural cover types selected were: corn, soybeans, green forage (hay & pasture), and forest. In particular, the objectives of the study were: (1) to study the effect of deletion of each of the twelve spectral channels as well as each of the wavelength regions (visible, near infrared, middle infrared, and thermal infrared), on the statistical separability and corresponding estimated probability of correct classification of the agricultural cover types. (2) To develop a criterion for a combination of wavelength regions, based on the estimation of its probability of correct classification of agricultural cover types. Based on this criterion, evaluate all possible combinations of wavelength regions in the subsets of one to twelve spectral channels out of the twelve available ones. (3) To investigate the effect of time on these results.

## LITERATURE REVIEW

Kumar (1972)[2] has done a thorough review of the general area of 'reflection and emission from plants'. The results of percent correct classification, obtained from the analysis of multispectral scanner (MSS) data by applying pattern recognition techniques, for a flightline divided into four classes (soybeans, corn, water and a mixture of stubble, diverted acres and pasture) were reported in the LARS annual report (1970)[3]. These are summarized as follows:

| Performance | Percent Correct Classification Using the Following Wavelength Bands | | |
|---|---|---|---|
| | 3 Visible<br>1 Reflective IR | 3 Visible<br>2 Reflective IR | 3 Visible<br>2 Reflective IR<br>1 Thermal IR |
| Training fields | 86.8 | 91.9 | 93.6 |
| Test fields | 82.8 | 83.9 | 86.4 |

Training fields = 4303 sample points Test fields = 7135 sample points.

ORIGINAL PAGE
OF POOR QUALITY

where

channel 1 = 0.40 - 0.44 μm, channel 2 = 0.5[illegible] - 0.58 μm,
channel 3 = 0.66 - 0.72 μm, channel 4 = 0.80 - 1.00 μm,
channel 5 = 1.50 - 1.80 μm, channel 6 = 8.00 - 14.0 μm.

Coggeshall and Hoffer (1973)[4] have analyzed the multispectral scanner data of a flightline having mostly forest. They have investigated the following in much detail: 1) determination of the optimum number of the 12 available multispectral scanner (MSS) wavelength bands to use for forest cover mapping with automatic data processing (ADP) techniques; 2) determination of the current capability to map basic forest cover types using MSS data and ADP techniques; and 3) determination of the relative utility, to forest cover mapping, of the four spectral regions available in the twelve channel MSS data (i.e., visible, and near, middle and thermal infrared).

They concluded from the tests of classification accuracy of six cover types of interest (deciduous forest, coniferous forest, water, forage, corn and soybeans), that the use of five wavelength bands would fulfill the dual requirements of adequate accuracy and moderate computer time. Their results also indicated that the thermal infrared wavelength region is desirable, but not necessary, for forest cover mapping, and that accurate classification of deciduous and coniferous forest cover can be achieved with the visible plus either the near or middle infrared spectral regions. However, the deletion of the thermal infrared region caused considerable confusion among the agricultural cover types.

Kumar and Silva (1974)[5] have investigated the statistical separability of the spectral classes of blighted corn in much detail, data quantity (168 fields having 18804 sample points in ten flightlines) and depth. They found that the greater the difference between the blight levels, the more statistically separable they usually were. In addition, they found that the spectral classes of corn (healthy and blighted) were most separable in the wavelength range 1.00 to 1.40 μm.

ORIGINAL PAGE IS
OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED

Bauer (1974)[1] has discussed the results of 'wavelength band selection', obtained in the Corn Blight Watch Experiment.

Kumar and Silva [6,7] analysed the multispectral scanner data in the wavelength range 0.4 to 11.7 μm for three flightlines. They found that in the subsets of one to six spectral channels, the combination of wavelength regions (where V, N, M and T denote the visible,near infrared, middle infrared and thermal infrared wavelength regions, respectively): V, VM, VNM, VNMT, VVNMT, VVNMMT, respectively, were found to be the best choices for getting good overall statistical separability of the agricultural cover types for the data acquired on July 16 as well as August 12. An effort was made to explain these results on the basis of spectral properties of agricultural cover types. The overall statistical separability of the agricultural cover types was found to be greater for the data of August 12 than the data of July 16. The author felt a definite need for a further analysis of similar nature to evaluate explicitly each spectral channel, each wavelength region and all possible combinations of wavelength regions, for statistical separability and the corresponding probability of correct classification.

## METHOD OF ANALYSIS

Multispectral scanner data in twelve spectral channels in the wavelength range 0.4 to 11.7 μm, collected with an optical-mechanical scanner at altitudes of 900 to 2100 meters (3000 to 7000 feet) over Western Indiana were analyzed by applying automatic pattern recognition techniques. The wavelength bands of these twelve spectral channels are given in Table I. The data of three selected flightlines, acquired in the middle of July of 1971, were analysed. Each of these three flightlines had fair or good amounts of each of the four agricultural cover types: corn, soybeans, green forage and forest. These three flightlines were selected carefully so that these combined could be considered to be representative of the four agricultural cover types in Western Indiana.

ORIGINAL PAGE IS
OF POOR QUALITY

Black and white photography and gray-scale printouts of the spectral channels of the flightlines were used to aid in locating the boundaries of the fields on the LARS (Laboratory for Applications of Remote Sensing, Purdue University) Digital Display*. Sufficient number of fields of each agricultural cover type were selected carefully so that they could be assumed to be representative of the flightline.

Using the same three flightlines and twelve spectral channels, an identical analysis was performed on the data acquired in the middle of August, 1971, to study the effect of time on the statistical separability of agricultural cover types. The multispectral scanner data was acquired on both dates (middle of July and middle of August) between 10:30 a.m. and 12:05 p.m. (local solar time). In addition, these data were of good quality and free from problems like lack of sufficient ground observations, excessive cloud cover, etc. The analysis was done for the data acquired in the middle of July and the middle of August, because corn and soybeans have reached their maximum vegetative growth by these times, and one month of time is sufficient for significant changes to occur in the spectral properties of agricultural cover types. The author wanted to avoid the analysis of data taken from late September on, because soybeans are harvested in September-October. The author tried to keep all the variables, other than time, uniform in the two (middle of July and middle of August) sets of data. For example, an effort was made to select the same field boundaries for the two sets of data. A total of more than 600 fields taken from three flightlines were analysed.

Each field was treated as an independent unit and the fields of the same agricultural cover type were put in the same class.

---

* *The LARS Digital Display is a specially designed image display system linked to an IBM 360 Model 67 using a cathode ray tube as the pictorial medium for gray scale multispectral imagery.*

The sample points within each field were highly correlated. The LARSYS** statistics algorithm[8] was used to compute the mean vector and covariance matrix (mean and standard deviation) of the classes. In the LARSYS statistics algorithm, cluster algorithm, and feature selection algorithm, each sample point is treated independently in order to make the system convenient and flexible for usage. A key assumption made in these algorithms is that the distributions of the classes are Gaussian. Histograms of the spectral classes defined above were used to check unimodality of the statistical distributions in individual channels. The classes were redefined to eliminate distinct multiple modes. Divergence is defined for any two density functions. In the case of normal variables with unequal covariance matrices, divergence in n spectral channels $C_1$, $C_2$,... $C_n$, is given[9] by

$$D(i,j|C_1,C_2,\ldots C_n) = 1/2\ \mathrm{tr}\{(\Sigma_i - \Sigma_j)(\Sigma_j^{-1} - \Sigma_i^{-1})\} + 1/2\ \mathrm{tr}\{(\Sigma_i^{-1} + \Sigma_j^{-1})(U_i - U_j)(U_i - U_j)^T\} \quad (1)$$

where

U and $\Sigma$ represent the mean vector and covariance matrix respectively: tr A (trace A) is the sum of the diagonal elements of A.

A modified form of the divergence $D_T$, referred to as "transformed divergence", has a behavior[8,10] more like the probability of correct classification than the divergence, D.

$$D_T = 2\{1 - \exp(-D/8)\} \quad (2)$$

Transformed divergence has been used throughout this study.

Although divergence only provides a measure of the distance between two class densities, its use has been extended to the

---

** *LARSYS is the earth resources data processing software system of the Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana.*

ORIGINAL PAGE IS
OF POOR QUALITY

multiclass case by taking the average over all pairs[11]. Let $D_{Tij}$ denote the divergence between classes i and j of a certain flightline, then the average divergence over all class pairs of four classes (each agricultural cover was treated as a separate class) is given by

$$D_{TAVG} = \frac{1}{6} \left[ D_{T12} + D_{T13} + D_{T14} + D_{T23} + D_{T24} + D_{T34} \right] \tag{3}$$

$$\text{Let } D_{TMIN} = \text{minimum of } \{D_{T12}, D_{T13}, D_{T14}, D_{T23}, D_{T24}, D_{T34}\} \tag{4}$$

Swain[8] (1972) has pointed out that one possible strategy is to select the subset of features for which the average transformed divergence, $D_{TAVG}$, is maximum. While this strategy is certainly reasonable, there is no guarantee that it is optimal. Another strategy is to maximize the minimum divergence, $D_{TMIN}$, i.e., to select the feature combination which provides the greatest separation between the hardest-to-separate pair of classes.

Let superscripts 1 and 2 with the symbol "$D_T$" denote the values of transformed divergence for the data acquired in middle of July and middle of August respectively. Let $D^1_{TMIN1}$, $D^1_{TMIN2}$, and $D^1_{TMIN3}$, be the values of $D_{TMIN}$ (see eq. (4)) in first, second and third flightline respectively for the data acquired in middle of July.

$$\text{Let } \bar{D}^i_{TAVG} = \frac{1}{3} \left[ D^i_{TAVG1} + D^i_{TAVG2} + D^i_{TAVG3} \right], \; i = 1,2 \tag{5}$$

$$\text{Let } \bar{D}^i_{TMIN} = \text{minimum of } \left[ D^i_{TMIN1}, D^i_{TMIN2}, D^i_{TMIN3} \right], \; i = 1,2 \tag{6}$$

The LARSYS feature selection processor was used to find $\bar{D}^1_{TAVG}$ and $\bar{D}^1_{TMIN}$ in all <u>possible</u> combinations of one to twelve spectral channels out of the available twelve.

Throughout this analysis, the combinations of one through twelve spectral channels were ranked so as to get the descending order of $\bar{D}^1_{TAVG}$ for the data of middle of July and middle of August respectively. In other words

$$\bar{D}^1_{TMAX} \{\text{subset of r spectral channels}\} = \max \{\bar{D}^1_{TAVG}\} \qquad (7)$$

maximized over all possible subsets of r spectral channels out of the available twelve for data of middle of July. From the values of the average transformed divergence, classification accuracy can be reasonably predicted from the results of Swain et.al. (1973)[10].

Table I gives the wavelength interval and the corresponding wavelength region of each of the twelve spectral channels. Tables II and III give, respectively, the effect of deletion of each of the twelve spectral channels in each of the four wavelength regions on $\bar{D}^1_{TMAX}$ as well as $\bar{D}^2_{TMAX}$.

To fulfill one of the main objectives of the study -- evaluation of all possible combinations of wavelength regions in the subsets of one to twelve spectral channels -- the following criterion is proposed:

Each of 12 available channels of the multispectral scanner can be placed in one of the four wavelength regions -- visible, near infrared, middle infrared and thermal infrared, as shown in Table I. Thus, any combination of spectral channels can be called as the corresponding combination of the wavelength regions. For example, channel combination 1,8,10 and 12 is called "combination of visible, near infrared, middle infrared and thermal infrared wavelength regions", and is denoted by V N M T. For a given combination of wavelength regions, for example V N M T;

ORIGINAL PAGE IS
OF POOR QUALITY

$D_{TAVG}$ and the corresponding values of $P_c$, using the curve of Swain et. al.[10], were calculated for all possible combinations of four spectral channels out of twelve available ones that constitute the combination V N M T. The mean of these values of $P_c$ was calculated for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels, and is shown in Table IV for the data of middle of July as well as middle of August.

## RESULTS AND DISCUSSION

The overall separability of green forage from the other agricultural cover types was found to be considerably lower than the corresponding separability of corn, soybeans and forest, because the standard deviation of the mean response of green forage was largest among the agricultural cover types. This is because there was much natural variability in the spectral characteristics of hay as well as pasture. The overall separability of forest from other agricultural cover types was found to be considerably higher than the corresponding separability of corn, soybeans and green forage. Green forage and corn were hard to separate, because of considerable overlap in the values of their mean response, due to the large standard deviation of green forage. In addition, it was harder to separate corn from soybeans for the data of middle of July than for the data of middle of August.

Table II shows that for greatest overall statistical separability, channel 7 (0.61 to 0.70 μm, red channel) seems to be the best channel. It should be pointed out that the predominant pigments of the plant leaf absorb in the vicinity of 0.44 μm, but only chlorophyll[12] absorbs in the red, in the vicinity of 0.64 μm. The reason for channel 7 being the best channel may be that there are significant differences in the chlorophyll content of different agricultural cover types, which give rise to differences in their mean response in channel 7, and hence a relatively large value of average transformed divergence between them. An additional reason may be that the red wavelength region is extremely favorable for qualitative and

quantitative description of soils[13].

Table II also shows that deletion of channel 7 reduces $P_c$ by about two percent for the data of middle of July as well as middle of August. The deletion of each of the other channels causes no reduction, or less reduction in the values of $P_c$, as compared to channel 7. Thus, deletion of any one of the twelve channels does not cause any substantial decrease in values of $P_c$ in the subsets of one to eleven channels.

As one would expect, Table III shows that the greatest separability of the agricultural cover types is obtained by using all of the twelve channels. However, an increase in the number of channels used in a classification algorithm requires a disproportionate increase in computer time[4]. Without doing a detailed analysis, it seems from Table III that the subset of five channels is likely to fulfill the dual requirements of adequate classification accuracy and moderate computer time. However, this conclusion is very preliminary because no cost benefit analysis for the data was done.

Table III shows that deletion of each of the wavelength regions causes the following maximum reductions in $P_c$ for the data acquired in the middle of July: visible (3.32, subset of four channels), near infrared (0.38, subset of ten channels), middle infrared (1.10, subset of two channels), thermal infrared (1.02, subset of four channels). The corresponding values of reductions in $P_c$ for the data acquired in the middle of August are: visible (2.07, subset of one channel), near infrared (0.41, subset of ten channels), middle infrared (1.16, subset of two channels), thermal infrared (0.39, subset of eight channels). Thus, it appears that deletion of the visible wavelength region causes more reduction in $P_c$, as compared to any of the other wavelength regions. The deletion of near infrared wavelength region apparently causes relatively small changes in the values of $P_c$.

Table IV shows that in the subsets of one to six spectral

channels, the combination of wavelength regions V, VM, VMT, VNMT, VVNMT, VVNMMT are found to be the best choices for the data of middle of July. Similarly, for the data acquired in the middle of August: T, NT, VNT or VMT, VNMT, VVNMT or VNMMT, VVNMMT are found to be the best choices. These results are similar to the results obtained by Kumar and Silva [6,7], although a different criterion of evaluation of combinations of wavelength regions was used by them. Obviously, all the seven channels in the visible wavelength region in this multispectral scanner (MSS) are not necessary for getting good separability of the agricultural cover types.

In the data of middle of July as well as middle of August, VNMT is found to be the best choice in the subsets of four channels. It indicates that each wavelength region is valuable in its own way; the visible wavelength region, for instance, is valuable because the predominant plant pigments absorb in this wavelength region. Because of the presence of water absorption bands in the middle infrared, surface geometry of the target and the moisture content of its top layers (of the order of micrometers) determine its reflectance in the middle infrared. This region is valuable because there are significant differences in the geometry of the surface and/or moisture content of top layers of the agricultural cover types. The near infrared wavelength region is useful because substantial contrasts between the agricultural covers and soils occur in this region. Thus, this region is especially useful when there are substantial differences in the percentage ground covers of the agricultural cover types. The thermal channel (channel 12) contains information about the radiant temperatures of the targets in the wavelength region 9.3 to 11.7 μm. There are found to be significant differences in the radiant temperatures of the agricultural cover types. The radiant temperature of a plant can be found by doing an energy balance on it, and it depends upon factors such as: radiation incident on the plant, plant geometry and size, spectral properties of the plant (including soil), percent ground cover, convection coefficient and transpiration rate of the plant, etc[2]. There are found to be differences in the values of the above variables

ORIGINAL PAGE IS
OF POOR QUALITY

for different agricultural cover types that give rise to differences in their radiant temperatures. Thus, in the subset of six spectral channels, irrespective of what other five channels were used, adding a thermal channel usually increased the overall separability of the agricultural cover types.

In conclusion, it should be said that determining which combinations of one, two,..., eleven spectral channels, out of twelve available spectral channels, give greatest overall statistical separability of the agricultural cover types is a complex problem, because statistical separability, in any given combination of spectral channels, depends upon many variables, such as quality of data in the spectral channels, quality and quantity of the ground truth available, time of acquiring the data, human decisions (number of fields, field boundaries to be selected, etc.) environmental variables, soil variables, etc.[2]. However, determining which combinations of one through six wavelength regions give greatest overall statistical separability of the agricultural cover types is a relatively less complex problem (Table IV). It should be pointed out, although the flightlines analyzed had considerably different characteristics than the flightline analyzed by Coggeshall and Hoffer[4] (Introduction), that many of the conclusions presented in this paper are the same as obtained by them. This means that, although the analysis was done for three flightlines, the results obtained may well be applicable to other flightlines having considerably different characteristics than these. The overall statistical separability of the agricultural cover types was found to be greater for the data of middle of August than for the data of middle of July. It should be noted that many of the results obtained from the analysis of the data of middle of July are the same as those obtained from the data of middle of August. This means that, although the analysis was done for the data acquired at two different times, the results obtained from this analysis may well be applicable to the data acquired at some other times of the year.

ORIGINAL PAGE IS
OF POOR QUALITY

ACKNOWLEDGEMENTS

The author gratefully acknowledges: the Laboratory for Applications of Remote Sensing, Purdue University, for their permission to use the multispectral scanner data, obtained under the NASA Grant Nº NGL 15-005-112; Dr. Nelson de Jesus Parada, the Director of the Instituto de Pesquisas Espaciais (INPE), for his assistance and authorization to publish this work; Dr. Celso de Renna e Souza for his continuous encouragement and assistance; Miss M. Niero and Miss S.M. Fonseca of INPE, Carlos Roberto de Souza & Luiz Rogério de Camargo of Instituto Tecnológico de Aeronáutica, S.J. dos Campos, SP, Brasil for their help in preparation of tables.

TABLE 1.

WAVELENGTH BANDS OF THE SPECTRAL CHANNELS

| Channel Nº | Wavelength Band (Micrometers) | Wavelength Region |
|---|---|---|
| 1 | 0.46 - 0.49 | visible |
| 2 | 0.48 - 0.51 | visible |
| 3 | 0.50 - 0.54 | visible |
| 4 | 0.52 - 0.57 | visible |
| 5 | 0.54 - 0.60 | visible |
| 6 | 0.58 - 0.65 | visible |
| 7 | 0.61 - 0.70 | visible |
| 8 | 0.72 - 0.92 | near infrared |
| 9 | 1.00 - 1.40 | near infrared |
| 10 | 1.50 - 1.80 | middle infrared |
| 11 | 2.00 - 2.60 | middle infrared |
| 12 | 9.30 - 11.70 | thermal infrared |

TABLE II. EFFECT OF DELETION OF EACH CHANNEL ON THE PERCENTAGE PROBABILITY OF CORRECT CLASSIFICATION

| When using a subset of | Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ (see eq.(7)) when using all the available channels (A) | Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when deleting a channel from the available channels (A) | Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when using all the available channels (B) | Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when deleting a channel from the available channels (B) |
|---|---|---|---|---|
| one channel | 84.63 | Same (84.63) except deletion of channel (ch.)7 reduced it to 82.64. | 86.18 | Same (86.18) except deletion of channel (ch.) 7 reduced it to 84.11. |
| two channels | 89.28 | Same (89.28) except deletion of ch. 7 and 10. Deletion of ch. 7 and ch.10 reduced it to 88.55 and 89.26 respectively | 91.88 | Same (91.88) except deletion of ch. 7 and 11. Deletion of ch. 7 and ch.11 reduced it to 91.57 and 91.09 respectively. |
| three channels | 91.58 | Same (91.58) except deletion of ch. 7,11 and 12. Deletion of ch.7, ch.11 and ch. 12 reduced it to 90.85, 91.44 and 90.72 respectively | 94.64 | Same (94.64) except deletion of ch. 3,8 and 11. Deletion of ch.3, ch. 8 and ch.11 reduced it to 94.52, 94.42 and 94.56 respectively. |
| four channels | 93.43 | Same (93.43) except deletion of ch.4,7,11 and 12. Deletion of ch.4, ch.7, ch.11 and ch.12 reduced it to 93.13, 93.11, 93.36 and 92.41 respectively. | 96.33 | Same (96.33) except deletion of ch. 4,8,11 and 12. Deletion of ch.4, ch.8, ch.11 and ch.12 reduced it to 96.28, 96.27, 96.23 and 96.25 respectively. |

Note: The effect of deletion of a channel in the subsets of five to twelve channels on the percentage probability of correct classification estimated from $\bar{D}_{TMAX}$, $P_c$, was rather small except for channel 12, i.e., the maximum reduction in $P_c$ = 0.20 for case (A) and 0.3 for case (B) except for channel 12. The effect of deletion of channel 12 can be found in the Table III. The values of $P_c$ were estimated from the values of $\bar{D}_{TMAX}$ using the curve of Swain and Ming (1973)[10].
(A) refers to data acquired in the middle of July. (B) refers to the data acquired in the middle of August.



ORIGINAL PAGE IS OF POOR QUALITY

TABLE III. EFFECT OF DELETION OF EACH WAVELENGTH REGION ON THE PERCENTAGE PROBABILITY OF CORRECT CLASSIFICATION

| Number of channels in the subset | Values of probability of correct classification estimated from $\bar{D}_{TMAX}$ (see eq(7) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ |
| one | 84.63 | 82.00 | 84.63 | 84.63 | 84.62 | 86.18 | 84.11 | 86.18 | 86.18 | 86.18 |
| two | 89.28 | 87.22 | 89.23 | 88.18 | 89.23 | 91.88 | 91.56 | 91.88 | 90.72 | 91.88 |
| three | 91.58 | 88.74 | 91.58 | 91.00 | 90.72 | 94.64 | 93.89 | 94.34 | 94.42 | 94.64 |
| four | 93.43 | 90.11 | 93.43 | 92.8 | 92.41 | 96.33 | 95.46 | 96.27 | 96.08 | 96.25 |
| five | 94.34 | 92.01 | 94.34 | 93.91 | 93.55 | 97.22 | 96.51 | 97.17 | 96.79 | 97.02 |
| six | 94.95 | np | 94.88 | 94.40 | 94.23 | 97.73 | np | 97.60 | 97.24 | 97.43 |
| seven | 95.33 | np | 95.22 | 94.78 | 94.68 | 98.02 | np | 97.75 | 97.39 | 97.73 |
| eight | 95.63 | np | 95.32 | 95.09 | 95.05 | 98.21 | np | 97.84 | 97.51 | 97.82 |
| nine | 95.89 | np | 95.62 | 95.26 | 95.31 | 98.30 | np | 97.90 | 97.60 | 98.02 |
| ten | 96.08 | np | 95.70 | 95.38 | 95.48 | 98.36 | np | 97.95 | 97.68 | 98.11 |
| eleven | 96.20 | np | np | np | 95.58 | 98.40 | np | np | np | 98.14 |
| twelve | 96.30 | np | np | np | np | 98.20 | np | np | np | np |

Note: 'np' denotes that it was not possible to have a combination of n (n = 1,2... 12) spectral channels after deleting the spectral channels in a particular wavelength region. This table gives the values of percentage probability of correct classification ($P_c$) estimated from the values of $\bar{D}_{TMAX}$ (see eq.(7); Swain and King (1973)).[10] $A_0$, $A_1$, $A_2$, $A_3$ and $A_4$ denote the values of $P_c$ when using all available channels; deleting spectral channels in the visible, near infrared, middle infrared and thermal infrared wavelength regions respectively for the data acquired in the middle of July. $B_0$, $B_1$, $B_2$, $B_3$ and $B_4$ denote corresponding quantities as $A_0$, $A_1$, $A_2$, $A_3$ and $A_4$ respectively for the data acquired in the middle of August.

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE IV. EVALUATION OF COMBINATIONS OF WAVELENGTH REGIONS

r = 1

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| V | 81.8 | 82.8 |
| W | 71.1 | 80.7 |
| X | 81.7 | 85.0 |
| T | 80.7 | 83.0 |

r = 2

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| VV | 85.0 | 88.4 |
| VW | 85.9 | 89.1 |
| VX | 87.5 | 90.5 |
| VT | 86.9 | 89.4 |
| WX | 77.0 | 86.1 |
| WT | 85.4 | 89.7 |
| XT | 84.4 | 91.1 |
| [illegible] | 85.4 | 87.6 |
| [illegible] | 86.7 | 90.5 |

r = 3

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| VVV | 88.5 | 89.4 |
| VVW | 87.7 | 91.8 |
| VVX | 85.4 | 91.8 |
| VVT | 88.2 | 90.2 |
| VWX | 85.0 | 91.0 |
| VWT | 86.6 | 91.4 |
| VXT | 85.5 | 92.1 |
| WXT | 84.1 | 91.1 |
| VVVW | 90.3 | 92.5 |
| VVVX | 87.6 | 92.4 |
| VVVT | 88.7 | 91.4 |
| VVWX | 88.3 | 92.0 |
| VVWT | 87.8 | 92.4 |
| VVXT | 87.8 | 92.2 |
| VWXT | 89.4 | 92.4 |
| [illegible] | | |

r = 4

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| VVVW | 90.5 | 93.3 |
| VVVX | 91.8 | 95.3 |
| VVVT | 91.7 | 95.8 |
| VVWX | 91.7 | 95.3 |
| VVWT | 91.7 | 96.0 |
| VVXT | 91.8 | 96.2 |
| VWXT | 92.0 | 95.2 |
| WXVT | 91.8 | 96.0 |
| VVVVW | 91.3 | 96.3 |
| VVVVX | 91.6 | 96.2 |
| VVVVT | 91.5 | 96.2 |
| VVVWX | 91.8 | 96.3 |
| VVVWT | 91.5 | 96.5 |
| VVVXT | 92.0 | 96.4 |
| VVWXT | 91.7 | 96.5 |
| VWXVT | 92.0 | 96.5 |
| VVVVWX | 92.2 | 96.3 |
| VVVVWT | 92.0 | 96.4 |
| VVVVXT | 91.8 | 96.3 |
| VVWXVT | 92.0 | 96.5 |
| VVVVWXT | 92.2 | 96.3 |
| cont. | | |

r = 5

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| 5V | 88.8 | 93.3 |
| (4V)W | 91.8 | 95.3 |
| (4V)X | 91.7 | 95.8 |
| (4V)T | 91.7 | 95.3 |
| WVXT | 91.7 | 96.0 |
| VVVWX | 91.8 | 96.2 |
| VVVWT | 92.0 | 95.2 |
| VVVXT | 91.8 | 96.0 |
| VVWXT | 91.8 | 96.0 |
| VWXVT | 91.8 | 96.3 |
| WXVVT | 91.6 | 96.2 |
| VVVVVW | 91.5 | 96.2 |
| VVVVVX | 91.7 | 96.2 |
| VVVVVT | 91.8 | 96.3 |
| VVVVWX | 91.8 | 96.3 |
| VVVVWT | 91.5 | 96.5 |
| VVVVXT | 91.0 | 96.4 |
| VVVWXT | 91.5 | 96.3 |
| VVWXVT | 91.5 | 96.3 |
| VVVVVWX | 92.0 | 96.4 |
| VVVVVWT | 91.7 | 96.3 |
| VVVVVXT | 92.0 | 96.5 |
| VVVWXVT | 91.8 | 96.4 |
| VVVVWXT | 91.8 | 96.3 |
| cont. | | |

r = 6

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| 6V | 93.4 | 95.4 |
| (5V)W | 92.8 | 96.1 |
| (5V)X | 92.3 | 95.2 |
| cont. | | |

r = 7

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| 7V | 89.5 | 94 |
| (6V)W | 92.4 | 96.6 |
| (6V)X | 92.5 | 96.7 |
| (6V)T | 92.4 | 96.4 |
| VVVVVW | 92.5 | 96.8 |
| VVVVVX | 92.6 | 96.7 |
| VVVVVT | 93.5 | 96.7 |
| VVVVWX | 92.5 | 96.9 |
| VVVVWT | 94.7 | 96.5 |
| VVVVXT | 93.5 | 96.5 |
| VVVWXT | 93.7 | 96.7 |
| VVWXVT | 93.5 | 96.8 |
| VWXVVT | 94.7 | 96.9 |
| VVVVVWX | 94.7 | 96.8 |
| VVVVVWT | 93.5 | 96.8 |
| VVVVVXT | 94.7 | 96.8 |
| VVVWXVT | 94.3 | 97.1 |
| VVWXVVT | 94.2 | 97.2 |

r = 8

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| (7V)W | 93.0 | 96.2 |
| (7V)X | 92.2 | 96.3 |
| (7V)T | 92.2 | 95.8 |

r = 9

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| (7V)WX | 92.6 | 96.6 |
| (7V)WT | 93.6 | 96.8 |
| (7V)XT | 94.7 | 96.8 |
| (7V)VW | 93.5 | 96.7 |
| (7V)VX | 95.6 | 96.9 |
| (7V)VT | 95.6 | 96.9 |
| (6V)WX | 94.7 | 97.0 |
| (6V)WT | 95.5 | 97.0 |
| (6V)XT | 95.6 | 97.1 |
| VVVVVWX | 95.6 | 97.3 |
| VVVVVWT | 95.8 | 97.3 |
| VVVVVXT | 95.8 | 97.3 |
| VVVVWXT | 95.8 | 97.5 |
| VVVWXVT | 95.8 | 97.5 |
| VVWXVVT | 95.9 | 97.7 |

r = 10

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| (7V)WX | 95.5 | 97.1 |
| (7V)WT | 95.8 | 97.1 |
| (7V)XT | 95.5 | 97.3 |
| (7V)VW | 95.9 | 97.5 |
| (7V)VX | 95.9 | 97.6 |
| (7V)VT | 95.8 | 97.6 |
| (6V)WXT | 96.1 | 97.6 |
| (6V)VWX | 96.1 | 97.7 |
| (6V)VWT | 96.2 | 98.1 |

r = 11

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| (7V)WXT | 96.3 | 98.2 |

r = 12

| | (A) $P_c$ | (B) $P_c$ |
|---|---|---|
| (7V)VWXT | 96.3 | 98.2 |

Note: r = subset of spectral channels. The column (A) denotes the values of $P_c$ for the data acquired in the middle of July. The column (B) denotes the values of $P_c$ for the data acquired in the middle of August to calculate $P_c$ for a combination of wavelength regions, for example, VWXT: $D_{TWX}$ was calculated for all possible combinations of spectral channels constituting this combination of wavelength regions. From the mean of these values, the probability of correct classification ($P_c$) was estimated using the curve of Swain and King[10] (1973). V, W, X and T denote visible, near infrared, middle infrared and thermal infrared wavelength regions respectively.
5V ≡ VVVVV, 4V ≡ VVVV etc.

ORIGINAL PAGE IS
OF POOR QUALITY

## REFERENCES

[1] M.E. Bauer, Ed., "Corn blight watch experiment final report", National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, TX, 1974.

[2] R. Kumar, "Radiation from plants - reflection and emission: A review", Purdue Univ., W. Lafayette, IN, AA & ES 72-2-2, Feb. 1972, 88 p.

[3] "Remote multispectral sensing in agriculture", Laboratory for Applications of Remote Sensing, Purdue Univ., W. Lafayette, IN, Ann. Rep., 1970, vol. 3.

[4] M.E. Coggeshall and R.M. Hoffer, "Basic forest cover mapping using digitized remote sensor data and automatic data processing techniques", Laboratory for Applications of Remote Sensing, Purdue Univ., W. Lafayette, IN, LARS Information Note 030573, 1973, 131 p.

[5] R. Kumar and L. Silva, "Statistical separability of spectral classes of blighted corn", Remote Sensing of Environment, vol. 3, pp. 109-115, June 1974.

[6] R. Kumar and L. Silva, "Statistical separability of agricultural cover types in subsets of one to twelve spectral channels", Proc. of Ninth Int. Sym. on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, Michigan, 1974.

[7] R. Kumar and L. Silva, "Separability of agricultural cover types by remote sensing in the visible and infrared wavelength regions", IEEE Trans. on Geoscience Elec., vol. GE-15, No. 1, Jan. 77, pp. 42-49.

[8] P.H. Swain, "Pattern recognition: A basis for remote sensing data analysis", Laboratory for Applications of Remote Sensing, Purdue Univ., W. Lafayette, IN, LARS Information Note 111572, 1972, 40 p.

[9] T. Marill and D.M. Green, "On the effectiveness of receptors in recognition systems", IEEE Trans. Inform. Theory, vol. IT-9, pp. 11-17, 1963.

[10] P.H. Swain and R.C. King, "Two effective feature selection criteria for multispectral remote sensing", in Int. Joint Conf. Pattern Recognition, 5 p., 1973; also Laboratory for Applications of Remote Sensing, Purdue Univ., W. Lafayette, IN, LARS Information Note 042673.

[11] K.S. Fu and P.J. Min, "On feature selection in multiclass pattern recognition", School of Electrical Engineering, Purdue Univ., W. Lafayette, IN, Tech. Rep. TR-EE 68-17, July 1968.

[12] D.M. Gates, H.J. Keegan, J.C. Schleter, and V.R. Weidner, "Spectral properties of plants", Appl. Opt., vol. 4, pp. 11-20, 1965.

[13] A.I. Obukhov and D.S. Orlov, Pochvovedeniye, 174, No. 2, 1964.