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COMPUTER–AIDED CLASSIFICATION FOR REMOTE SENSING IN AGRICULTURE AND FORESTRY IN NORTHERN ITALY

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ABSTRACT

A set of results concerning the processing and analysis of data from LANDSAT satellite and airborne scanner is presented. The possibility of performing inventories of irrigated crops - rice, planted groves - poplars, and natural forests in the mountains - beeches and chestnuts, is investigated in the Po valley and in an alpine site of Northern Italy. Accuracies around 95% or better, 70% and 60% respectively are achieved by using LANDSAT data and supervised classification.

Discrimination of rice varieties is proved with 8 channels data from airborne scanner, processed after correction of the atmospheric effect due to the scanning angle, with and without linear feature selection of the data. The accuracies achieved range from 65% to more than 80%

The best results are obtained with the maximum likelihood classifier for normal parameters but rather close results are derived by using a modified version of the weighted euclidian distance between points, with consequent decrease in computing time around a factor 3.

1. INTRODUCTION

Investigation of the possibility of performing selective acreage estimations from LANDSAT satellite data is among the main objectives of the AGRESTE Project [1] sponsored by the European Communities for application of remote sensing to agriculture and forestry. Inventory of given agricultural and forestal species under European conditions requires to consider extensions which are often rather reduced with regard to LANDSAT resolution. This in turn leads to devote much work and care to prepare the ground truth documents, to divide the continuous areas into discrete elements following the scanning grid of the satellite and to compare (overlay) quantitatively the discrete document obtained with the classification results.

The studies presented here, performed with well known classification methods, will rely upon the preceeding considerations. The concept of supervised classification is applied, although an unsupervised clustering technique is introduced in one case as a complementary method.

The first method used, is the so-called "maximum likelihood" scheme (referred to henceforth as M.L.) for class distributions described by normal parameters, where the a priori probability distributions for the classes are assumed to be equal for all classes, which is a reasonable assumption when applying Bayes' inversion rule in a supervised classification context [2]. The vector to be classified is then attributed to the class for which the membership probability is maximum.

The second method used can be considered as formally identical to the M.L. scheme, but with the assumption that all the variance-covariance matrices describing the class distributions are diagonal. From another point of view it can be seen that the method calculates the euclidian distances between any vector to be classified and the mean vectors of the classes of interest, it then weighs the distances by the variance of the classes as in ref. [3]; lastly it constructs the following distance between the vector and class C:

$$\sum_{i=1}^{n} \frac{d_i^2}{v_i} + \ln \prod_{i=1}^{n} v_i,$$

where d_i is the euclidian distance for channel i, v_i is the variance for channel i, n is the number of channels (dimensions) and the first term is the weighted euclidian distance used in ref. [3]. The unknown vector is consequently assigned to the class for which the distance just described is minimum. This second method is simpler and much less time-consuming than the M.L. method and will be referred to henceforth as the "modified euclidian distance" (M.E.D.).

As a matter of fact, the AGRESTE Project is actually devoted to the study by remote sensing of three given "targets": rice as a crop present in Southern France and Northern Italy, planted poplar groves in flat areas in the same zones and natural forests (mainly beeches) over mountainous zones covering the frontier between the two countries. The project is carried out in collaboration with various French and Italian institutes and the results illustrated hereafter deal with typical areas within the Italian test sites studied with the methods just described.

A further objective of the AGRESTE Project regards the feasibility of discrimination between different varieties of the same agricultural crop, particularly discrimination between varieties of rice. Up to now, the only way to reach this objective, even to a limited extent, is to use data from airborne scanners; in fact the reduced dimensions of the controlled rice fields available for this scope and the insufficient spectral resolution of LANDSAT do not allow the use of satellite data for this study at the time being. Results of classification of rice varieties will then be described, using M.E.D. and M.L. schemes, together with linear feature selection by principal components analysis; correction of the variation of the atmospheric effect due to the scan angle will also be introduced following the so-called "long track averaging" procedure applied to the mean and the variance of the data.

2. RICE AREAS

The test site for rice studies is located South-West of Milan in a flat area between the Po river and its tributary, the Ticino. The ground truth was prepared in collaboration with Ente Nazionale Risi, Mortara, starting from catastal maps at the scale 1:6000, updated for rice fields location. The surface of the rice fields was calculated, with a maximum error evaluated to 2%, for the control area displayed in Fig.1, the total acreage of which is about 50 km^2.

As the rice fields are flooded every year from the beginning of May, the best estimate of rice areas is reached by a simple level slicing on the data of channel 7 (near infrared) of LANDSAT in order to put in evidence the water bodies. This is easily done by starting from an accurate examination of the histogram of channel 7 values for a LANDSAT scene acquired within the month of May. Fig.2 presents the result of such a procedure applied to data from a scene of May 10th, 1973, for the same area as in Fig.1. The rice fields are split up in many fragments, some perhaps only several pixels of LANDSAT size; it was not attempted therefore to grid the control area following the pixels of the satellite, but it is seen that the individual fields are recognized fairly well, although in one case a flooded meadow is obviously confused with rice and in some other cases rice fields, not yet flooded on May 10th, 1973, are not recognized.

By taking these facts into account, one finds that the recognized rice area (39.6% of the total area) compares to the ground truth rice area (40.7% of the total area) with an error less than 3%. Other water bodies, like streams and lakes, will be of course included in the rice inventory by this method, but a further processing of the same area acquired by the satellite after the growth of rice allows these areas to be excluded from the bulk results.

3. PLANTED POPLAR GROVES IN FLAT AREAS

3.1 Ground truth preparation

The ground truth document has been set up by Istituto di Sperimentazione per la Pioppicoltura, Casale Monferrato (I.S.P.), from an infrared aerial coverage, scale 1:10,000, which was done in August 1975, along the Po river at the level of the town Valenza, about 100 km downstream from Turin. The zone has an acreage of about 45 km^2 and is typical of poplar cultivation in Italy, which is concentrated to about 25% along the Po river and assumes a great importance in the production of wood pulp for paper. An exhaustive conventional photo interpretation of all the poplar groves was then done by research workers of the I.S.P. who were able to group poplar groves into four classes from the points of view of age and percentage of ground coverage [4]:

- groves of one year,
- young groves (age 2 - 3 years) with less than 25% ground coverage,
- intermediate groves (age 4 - 6 years) with 25 - 75% ground coverage,
- adult groves (age 7 years and more) with over 75% ground coverage.

The poplar groves were then reported in two comprehensive classes on the available U.T.M. map, scale 1:25,000:

- class 1 grouping all the young groves with ground coverage up to 25%,
- class 2 grouping intermediate and adult groves with ground coverage over 25%.

The global error at this stage is estimated at 2 - 3% of the groves' acreage.

3.2 Discrete ground truth construction

The reference map so constructed was lastly gridded into discrete elements corresponding to the pixels of LANDSAT and stored on magnetic tape to be compared afterwards with the classification results. The gridding was done by following an iterative process between reference map and classification results in order to ascertain the direction of the satellite scanning on the map and the location of some "one pixel" marks both on map and LANDSAT data. The interpreted areas were then obtained from the corresponding discrete contours (given as input) by running a contour-follower routine. As already specified, the overall accuracy of the above mentioned procedure is crucial for the reliability of the classification results stated afterwards, on account of the reduced dimensions of the individual areas studied (even one pixel size in extreme cases). It will be seen by comparing Figs.3 and 4 that the accuracy necessary for that scope was achieved. Figs.3 and 4 successive figures are photographs of grey level images from a cathode ray tube unit. Fig.3 represents a discrete ground truth display of the Po river, poplar class 1 and poplar class 2.

3.3 Classification methodology

The general idea was to perform the training of the algorithms in a few limited zones and thus to check, from a rather operative point of view, the effectiveness of the classification methods for the whole control area.

The training sets were determined after a preliminary clustering of the data of the whole area using euclidian distance between points as similarity measure [5], in order to put in evidence suitable clusters of pixels in the sense of uniformity and geographical location. They were then cleaned from marginal or anomalous points in order that they should exhibit unimodal or nearly unimodal distributions. The training sets retained for poplars are seen on Fig.3; they both belong to class 2 mentioned in section 3.1. It was not possible to retain training sets for class 1 because the insufficient ground coverage - owing to the variability of the ground conditions - causes dispersion in the data and hence in the classification results. Training sets were also determined for unidentified but homogeneous clusters outside the poplar groves and for the Po river, so that an exhaustive classification of the area became possible by using one class "poplars", one class "water" and three unlabelled homogeneous classes.

The classification methods utilized were the "maximum likelihood" (M.L.) scheme as developed by Borden et al. [6] and the "modified euclidian distance" scheme (M.E.D.) (see section 1) which were both run without any threshold for the classes.

3.4 Classification results

They are shown in Tables 1 and 2, some of them are displayed in Fig.4. Tables 1 and 2 are the so-called "performance matrices" between ground truth and classification for M.L. and M.E.D. methods. They are computed by comparing the discrete ground truth map and the classification results. They are organized in one row for each ground truth category and give the percentage of pixels well classified into that category and misclassified into the other categories. In the present case the poplar classes 1 and 2 were classified into a single poplar class for the reasons stated in section 3.3.

A study already done, partly over the same zone [7], showed that by merging together three suitable LANDSAT scenes (acquired on June 15th, July 3rd and September 13th, 1975) it was possible to recognize the older poplar groves (class 2) with an accuracy better than 80% and to discard almost completely the younger groves classified within the single poplar class. This discrimination is important on account of the fact that the older class (from 4 years age) contains all the amount of wood available each year for industrial needs.

As an improved procedure was available in the meanwhile for ground truth construction and overlay, a more accurate study was undertaken with the "best" among the three scenes, i.e. June 15th, 1975, in order to see the limits of single scene processing for this problem. The trends of the results are very similar for both M.L. and M.E.D. methods. About two thirds of class 2 poplars are classified as poplars while only a quarter of class 1 is recognized. Misclassifications occur also between poplars and water but this is due almost entirely to the difficulty to separate properly the Po river from the neighbouring poplar groves on the discrete ground truth document (it is recalled that the I.F.O.V. of LANDSAT is about 80 x 80 m^2). The class labelled "others" collects the three unidentified homogeneous classes referred to in section 3.3.

As a supplementary information, the ratios

$$\frac{\text{number of pixels classed into a given category}}{\text{number of pixels actually present in that category}}$$

are given in percentage for each classed category. The comparison of the two methods shows that the M.L. scheme is somewhat better but with the drawback of much larger computing time (25 s CPU time instead of 10 s for M.E.D., for classifying 9600 four-dimensional vectors into five classes, with an IBM 370/165 computer).

Fig.4 presents the graphic display of some important data of Table 1: the ground truth of the Po river (dark grey), the older poplars class 2, recognized as such (white), the older poplars not recognized (intermediate grey) and the younger poplars class 1 recognized as such (light grey). Other data were not displayed in order to avoid confusion of grey levels on the photograph.

4. NATURAL BEECH FORESTS IN MOUNTAINOUS AREAS

An inventory of natural beech forests in Northern Italy is important because it is thought that beeches could partially substitute poplars for the production of wood pulp. Classification of beeches in mountainous regions and discrimination between beeches and other deciduous trees growing in the same areas, especially chestnut trees, presents however a higher degree of difficulty than does the classification of planted poplar groves. A study was conducted over a typical area, about 90 km^2, containing differences of level from 800 to 2000 m and ground slopes up to 35%. Beeches, chestnuts, are present at the junction of two valleys (Vallone dell'Arma and Val Demonte) situated approximately 20 km East-South-East of the town Cuneo.

The major part of what has been said in sections 3.1 and 3.2 about the ground truth work remains valid here, apart from the fact that the conventional photo interpretation of beech and chestnut forests, made in collaboration with the Istituto Nazionale Piante da Legno, Turin, was not exhaustive; about 50% of the area containing mainly forests was indeed not characterized. The ground truth document containing only the characterized zones is seen in Fig.5.

4.1 Classification methodology

The procedure was similar to the one described in section 3.3, but with some differences. Because of the mountainous topography of the site, separate trainings of the classifier were done respectively in sunny and shadowy zones for beeches while a single training was sufficient for chestnuts and meadows. The training sets are seen on Fig.5.
On the other hand the clustering approach to define homogeneous unlabelled classes was not successful in this case on account, probably, of the complexity of the ground conditions; as the ground truth was not exhaustive, membership thresholds had to be imposed to the classes. The determination of thresholds for classes is always somewhat arbitrary; in the present case two suitable LANDSAT scenes were available (July 3rd and September 13th, 1975) and the thresholds were fixed empirically in order that the extensions of the various classes were found as close as possible in the two classifications and similarly as close as possible from the ground truth extensions. Only the M.L. method was applied for this problem and the thresholds were defined as a fraction of the maximum membership probability for each class.

4.2 Classification results

They are given as performance matrices in Tables 3 and 4 for the two LANDSAT scenes utilized, respectively July 3rd and September 13th, 1975 and for the zones effectively characterized on the ground truth. It is seen that the discrimination between beeches and chestnuts is rather good, although the two species present in the ground truth are far from being entirely recognized. The last row in the tables has the same meaning as explained in section 3.4. The results are, however, noticeably better with data of July 3rd from both points of view of inventory and discrimination between beeches and chestnuts, due to a more favourable period of vegetation.

Fig.6 displays the classification results for these data. It is seen, as already said, that the ground truth does not cover the whole classified area although the results obtained within the controlled zones can be very likely extrapolated outside, at least as a global trend. The discrimination between beeches and chestnuts is clearly visible and small isolated chestnut woods on the valley floor are also recognized. Fig.7 is a display of three types of data of the performance matrix in Table 6: beeches well classified as beeches (white), beeches not recognized as beeches - i.e. classified as "others" or left unclassified (light-grey), and "others" classified as beeches (dark grey).

5. DISCRIMINATION OF RICE VARIETIES WITH AIRBORNE SCANNER DATA

5.1 Characteristics of the data

The data were acquired on August 7th, 1975, between 9.11 and 10.32 o'clock in the morning by a Bendix M^2S scanner at a date on which the various rice varieties should be in the flowering stage, considered to be favourable for the scope of the operation. The technical data of the scanner are reported in Table 5. The data from channels 1, 2 and 10 were not used, however, due to unacceptable level of noise. The resolution of the data at the altitude of 1500 m is 3.8 m. The flight was done in the region referred to in section 2, to the South of the town of Mortara; the strip of data processed here covers a zone approx. 3 km^2 in acreage where six rice varieties are present, labelled in the following way on the ground truth document (Fig.8):

Gritna is labelled as G, Balilla Grana Grossa as B, Arborio as A, Carnaroli as C, Rocca as RC, Romeo as RO.

The other symbols in Fig.8 correspond to:

Corn for M, wet meadows for MR and other items - no vegetation - for O.

5.2 Ground truth preparation

The work was done in collaboration with Ente Nazionale Risi, Mortara. The final document (Fig.8) was prepared following the procedure described above but in a much easier context owing to the resolution of the data. All the rice fields present in the strip were not characterized from the point of view of rice variety; the black parts of Fig.8 (apart from roads and lanes in the fields), correspond to fields containing unidentified varieties or mixtures of varieties, which often occur in the studied zone. All the black parts of Fig.8, including this time roads and lanes, visible as straight lines, are then considered as uncharacterized areas on the ground truth map. Fig.8 is a composition of grey levels but it was obviously not possible to represent each ground truth class by a given grey level.

5.3 Classification methodology

The classification was this time exhaustive, including also the zones uncharacterized on the ground truth. No membership threshold was applied to any of the classes and no point was therefore left unclassified. The training of the algorithms was done, as above, on little portions of the ground truth classes as seen in Fig.8. Care was taken that the statistical distributions in the training sets be nearly unimodal although training sets of the same ground truth class could present noticeable differences between the respective distributions. Better global results were obtained, however, with the M.L. method by merging together all the sub-distributions of the same class than by processing such "sub-classes" separately. The opposite was true, on the average, with the M.E.D. method, particularly class A and class M were divided respectively into three sub-classes.

5.4 Atmospheric corrections

As the total scan angle of the Bendix M^2S scanner is 100°, it is well known that the variation of the thickness of the atmosphere between the scanner and the ground along a scan line has a systematic effect on the data acquired and may then cause a degradation of the classification results. The "long track averaging" procedure used here to correct this effect, assumes that, in absence of the above mentioned atmospheric effect, the mean and variance for each channel along a column of data (i.e. following the flight axis) would have the same value for all the columns (i.e. from edge to edge in the strip of data acquired). The routine set up calculates then in a first step the mean and the variance of the columns from edge to edge of the strip and successively transforms in a second step the data of each column in order that all the columns have the same mean and variance. This procedure is repeated separately for each channel. As a matter of fact, for practical reasons, the columns are grouped five by five, in the first step and the curves describing the variation of column mean and column variance are obtained by an eight-order polynomial fitting. The correction on the variance has proved to be useful to correct what appears as a lack of contrast towards the edges of the strip in a somewhat accurate visualization of the raw data.

5.5 Principal components analysis

A linear feature selection has been proved by principal components analysis, following Borden et al. [6]. In other words, the linear transformation applied to the data is constructed on the criterion of minimum information loss in the sense of the variance of the data. The transformation matrix is formed by a suitable number (depending on the data reduction desired) of eigen vectors of the variance-covariance matrix calculated over the whole area studied. More details cannot be given in a condensed paper on this well known method.

5.6 Outline of the results

The complete results are displayed in Tables 6 to 11, where UC means uncharacterized areas on the ground truth. They will be briefly commented here. The best result was obtained, as expected, with the M.L. method using all the 8 channels available (Table 6). It is seen that the discrimination is on the average very good between rice varieties on the one hand, between rice and other vegetal species on the other hand. The percentage of ground truth classified as such varies from 65 to 83%, apart from variety RO. The feature selection by P.C. analysis from 8 to 5 dimensions affects very little the results (Table 7), but the calculation time is decreased from 29 min. to 18 min. (CPU time - 134320 pixels processed); the fraction of the total variance conserved in the transformation is 99.2%. The raw classification results are displayed on Fig.9 for this last case. It is seen that the ground truth should be modified in order to contain all the roads and lanes actually present, which would probably improve the percentage of well classified pixels on the diagonal of the performance matrices. It is also seen that the uncharacterized rice fields (in black) on the ground truth are mainly classified as mixtures of varieties with the exception of zones where rice was not recognized; it must be said in this respect, that other varieties, not identified on the ground truth, are present in the same region and were not sampled here.

Tables 8 and 9 contain the results obtained with the M.E.D. method. It will be seen from what has been said on the M.E.D. scheme in section 1, that the linear transformation defined by P.C. analysis, but retaining the dimensionality of the space (i.e. 8 dimensions) should improve the results of the method because it has the tendency to decouple the variables as the global variance-covariance matrix of the whole area becomes diagonal. Table 9 presents the results for such a procedure and the comparison with Table 8 is conclusive. The results are not as good as those obtained with M.L., especially for varieties C and RC, but the calculation time is reduced from 29 min. (or 18 min.) to 5.5 min.

All the results commented up to now were obtained after performing on the data the atmospheric correction described in section 5.4, applied to both mean and variance of the data. Table 10 contains results with M.L. method, 5 dimensions, without atmospheric correction, which compare with Table 7 in a very conclusive way, especially for varieties C, RC and RO located partly or entirely, towards the edge of the data strip. The correction was applied only on the mean for the results displayed in Table 11 and the effect, although limited to second order, is however noticeable by comparing Table 11 to Table 7.

6. CONCLUSIONS

Elements of an answer to some of the questions raised in the framework of the AGRESTE Project have been specified along this study. Acreage estimation of rice-cultivated areas has proven to be possible, from LANDSAT data, with an accuracy better than 95%, when using a scene acquired during the period when the rice fields are flooded. Other studies showed that the accuracy is decreased to 80% when data belonging to the growing season are processed separately.

The recognition of planted poplars in the Po Valley was not exhaustive, as about 70% of the poplar groves suitable for industrial needs are well recognized by a single scene processing but the accuracy increases to 80% or even more when several scenes acquired at different periods are processed together. The inventory of natural beech forests in an alpine site to the South-West of Turin proved to be more difficult although about 60% of the beeches and chestnuts present in the ground truth were recognized and the discrimination between the two species was accurate to about 80%. From a more operative point of view it must be added that in both cases the sampling was done on reduced parts of the studied zones and that the construction and overlay of discrete ground truth documents on the classification maps gave satisfactory results even on areas as reduced as some pixels in size.

Six rice varieties were well recognized in proportions ranging from 65% to more than 80% by using airborne scanner data including a thermal channel, acquired during the flowering period. Correction of the data from the atmospheric effect introduced by the scan angle brings a noticeable improvement in the results, the long track averaging procedure applied to the mean and the variance of the data was found suitable in this respect. The computing time necessary for the last study was reduced by a factor 1.6 when using a linear feature selection determined by principal components analysis.

Lastly, the comparison along the study between the maximum likelihood method and a modified version of a classifier using a weighted euclidian distance, showed that, at the price of some reasonable loss of accuracy, the computing time can be reduced practically by a factor ranging from 2.5 to 3.5.

As a last remark, the authors are conscious of the fact that the reliability of the above results would be increased by studies over larger areas; these studies are under way and will constitute the next step of the AGRESTE Project.

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Results / G.T.	Water	Poplars	Others
Water	76.9	4.1	19.1
Poplars class 1	2.5	27.4	70.1
Poplars class 2	0.6	70.4	29.0
Others	4.5	10.7	84.8
Total classed/ total present	125	83.6	104

Table 1 : Poplars performance matrix for M.L. method

Results / G.T.	Water	Poplars	Others
Water	78.9	3.9	17.2
Poplars class 1	2.7	24.4	72.9
Poplars class 2	0.6	66.6	32.7
Others	4.9	8.9	86.2
Total classed/ total present	131	75.3	106

Table 2 : Poplars performance matrix for M.E.D. method

Results / G.T.	Low veg.	Chest.	Beeches	UC
Low veg.	38.4	8.9	10.5	42.2
Chest.	13.0	56.7	11.7	18.6
Beeches	6.7	15.5	56.3	21.4
UC	35.1	11.6	15.7	37.7
Total classed/ total present	75.2	149	71.5	

Table 3 : Beeches - chestnuts performance matrix for M.L., July 3, 1975. UC: unclassified

Results / G.T.	Low veg.	Chest.	Beeches	UC
Low veg.	53.8	8.7	10.2	27.3
Chest.	12.3	50.4	20.8	16.5
Beeches	13.3	21.1	49.3	16.2
UC	23.8	9.3	14.2	52.8
Total classed/ total present	94.6	160	66.2	

Table 4 : Beeches - chestnuts performance matrix for M.L., Sept. 13, 1975. UC: unclassified

		Channel Nr.	Center (μm)	Width (μm)	Channel Nr.	Center (μm)	Width (μm)
Scan angle:	100°	1	0.410	0.06	7	0.680	0.04
		2	0.465	0.05	8	0.720	0.04
Roll-compensation:	±10°	3	0.515	0.05	9	0.815	0.09
		4	0.560	0.04	10	1.015	0.09
Geometric resolution	$2.5 . 10^{-3}$ rad.	5	0.600	0.04	11	11.0	6.0
		6	0.640	0.04			

Table 5 : BENDIX M^2S scanner technical data

	G	B	A	MR	M	C	RC	RO	O
G	71.4	7.9	9.8	0.0	2.4	0.2	2.5	0.2	5.4
B	2.9	76.4	1.2	0.1	3.1	1.7	0.4	0.3	13.9
A	11.3	1.3	66.8	0.0	3.9	0.2	3.2	0.9	12.3
MR	0.1	0.0	0.4	83.5	2.2	0.0	0.1	0.0	13.8
M	0.2	0.0	0.2	0.1	80.1	0.0	0.1	0.0	19.2
C	0.8	10.3	0.3	0.0	1.0	64.7	14.7	2.5	5.6
RC	0.9	1.3	4.5	0.0	1.3	0.5	78.3	10.2	3.0
RO	0.2	1.7	8.8	0.0	1.2	0.1	26.0	51.2	10.8
O	0.5	1.2	0.1	1.6	2.8	0.1	0.1	0.1	93.5
UC	2.0	12.0	3.4	0.4	13.8	3.6	1.9	0.6	62.3
Tot.cl./ tot.pres.	105	97	83	89	108	68	210	84	

Table 6 : Rice varieties - Performance matrix for M.L. 8 channels

	G	B	A	MR	M	C	RC	RO	O
G	69.1	7.4	11.5	0.0	3.0	0.6	3.1	0.2	5.0
B	2.9	74.4	1.2	0.0	4.4	2.7	0.4	0.3	13.6
A	15.2	1.0	63.7	0.0	6.4	0.2	2.8	0.9	9.7
MR	0.0	0.0	0.5	85.4	3.9	0.0	0.0	0.0	10.1
M	0.3	0.0	0.3	0.2	78.0	0.0	0.1	0.0	21.1
C	1.1	11.7	0.4	0.0	1.2	62.4	14.6	2.8	5.7
RC	2.1	1.3	5.4	0.0	1.3	0.6	76.3	10.3	2.5
RO	0.2	1.5	11.9	0.0	1.2	0.2	27.0	47.9	9.7
O	1.1	1.4	0.4	1.4	5.4	0.2	0.2	0.1	89.7
UC	2.5	11.9	3.6	0.4	17.6	4.0	2.0	0.5	57.4
Tot.cl./ tot.pres.	111	96	82	90	117	67	204	83	

Table 7 : Rice varieties - Performance matrix for M.L. 5 dimensions

	G	B	A	MR	M	C	RC	RO	O
G	46.3	10.3	19.9	0.0	7.0	1.6	10.4	0.0	4.4
B	2.1	73.4	0.7	0.0	2.7	11.6	0.8	0.1	8.6
A	20.8	4.4	55.3	0.2	6.5	0.3	2.5	2.9	7.1
MR	0.1	0.0	0.2	74.3	5.5	0.0	0.0	0.0	20.0
M	1.9	14.8	1.0	0.3	57.7	0.1	0.0	0.0	24.1
C	2.7	28.4	1.2	0.0	1.6	46.4	12.4	0.1	7.1
RC	1.4	9.5	26.6	0.0	1.0	0.6	51.3	8.6	1.0
RO	0.9	20.5	36.4	0.0	0.8	0.3	15.7	24.2	1.2
O	0.5	5.7	0.5	10.5	11.1	0.8	0.3	0.0	70.7
UC	3.0	19.2	3.6	2.1	22.5	5.5	1.1	0.2	42.9
Tot.cl./ tot.pres.	103	132	95	103	103	61	174	45	

Table 8 : Rice varieties - Performance matrix for M.E.D. 8 channels

	G	B	A	MR	M	C	RC	RO	O
G	61.1	6.6	13.0	0.0	3.5	0.1	0.8	0.1	14.9
B	1.9	65.8	0.5	0.0	4.6	1.1	0.3	0.1	25.8
A	13.4	1.8	60.4	0.0	3.9	0.0	2.0	0.4	18.1
MR	0.3	0.0	0.2	68.2	0.7	0.0	0.0	0.0	30.6
M	0.2	3.2	1.9	0.0	69.3	0.0	0.0	0.0	25.4
C	1.4	23.5	0.5	0.0	2.2	43.4	10.9	0.8	17.2
RC	1.5	2.7	20.8	0.0	0.7	0.1	56.7	9.9	7.5
RO	1.1	5.4	26.8	0.0	0.7	0.0	20.1	29.8	16.0
O	0.2	1.8	0.3	0.4	1.6	0.0	0.0	0.0	95.5
UC	2.3	15.1	3.4	0.2	10.5	2.3	0.7	0.3	65.3
Tot.cl./ tot.pres.	98	104	89	70	100	45	150	48	

Table 9 : Rice varieties - Performance matrix for M.E.D. 8 dimensions after P.C. transformation

	G	B	A	MR	M	C	RC	RO	O
G	61.4	6.7	6.8	0.0	4.6	1.4	14.1	0.9	4.0
B	8.7	55.9	1.4	0.0	4.3	18.0	0.4	0.1	11.2
A	6.3	3.5	64.5	0.1	4.1	0.4	6.0	4.5	10.6
MR	0.2	0.6	0.3	87.0	1.7	0.0	0.0	0.0	10.3
M	0.4	2.4	20.0	0.0	72.8	0.0	0.2	0.1	4.1
C	2.6	30.6	3.5	1.1	15.4	29.3	0.6	0.0	16.8
RC	18.6	0.0	3.3	0.0	10.4	3.7	41.6	0.4	22.1
RO	22.6	0.0	25.2	0.0	1.7	0.0	3.7	15.7	31.1
O	7.2	6.0	0.1	2.9	4.4	0.4	0.3	1.0	77.5
UC	2.8	19.7	6.7	0.8	21.1	8.4	2.4	0.7	37.2
Tot.cl./ tot.pres.	134	104	110	108	145	51	102	37	

Table 10 : Rice varieties - Performance matrix for M.L. 5 dimensions without atmospheric corrections

	G	B	A	MR	M	C	RC	RO	O
G	69.9	9.7	9.8	0.0	3.3	1.0	2.2	0.2	3.8
B	4.4	75.2	0.7	0.0	4.8	6.9	0.6	0.4	7.1
A	16.1	2.9	59.7	0.1	7.5	0.3	3.5	4.6	5.4
MR	0.2	0.3	0.3	86.9	2.9	0.0	0.0	0.0	9.4
M	1.0	0.2	0.7	0.2	81.5	0.0	0.1	0.0	16.1
C	1.8	14.0	0.2	0.0	0.9	66.9	12.8	0.3	3.1
RC	3.6	1.5	12.2	0.0	1.0	1.3	68.1	11.7	0.7
RO	1.0	6.1	22.0	0.0	1.9	0.7	36.9	30.0	1.4
O	2.1	3.5	0.3	1.8	6.7	0.7	0.5	0.1	84.3
UC	4.2	18.0	2.8	0.1	17.2	5.1	2.1	1.0	49.5
Tot.cl./ tot.pres.	125	105	81	91	122	76	201	65	

Table 11 : Rice varieties - As in table 10 but atmospheric corrections on the mean only

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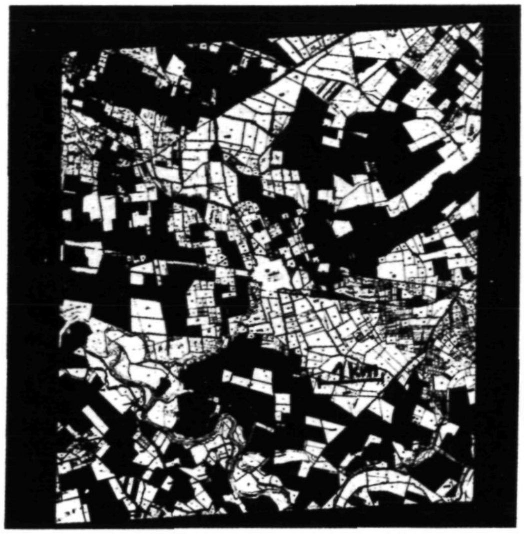

Fig. 1 : Ground truth for rice (in black). Approx. scale 1:130,000

Fig. 2 : Rice fields (in black) recognized by level slicing on channel 7 May 10th, 1973

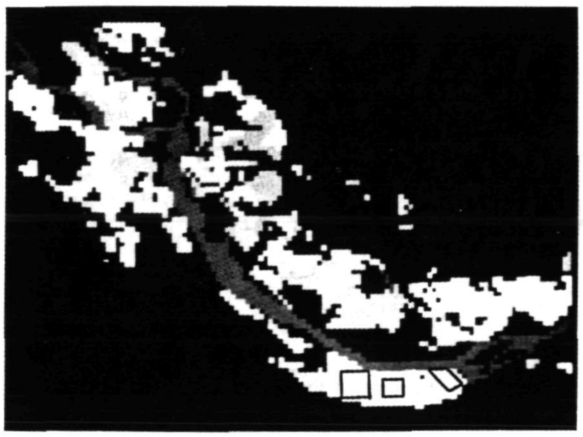

Fig. 3 : Ground truth for poplars. Po river: dark grey; class 1 poplars: light grey; class 2 poplars: white. Approx. scale 1:120,000

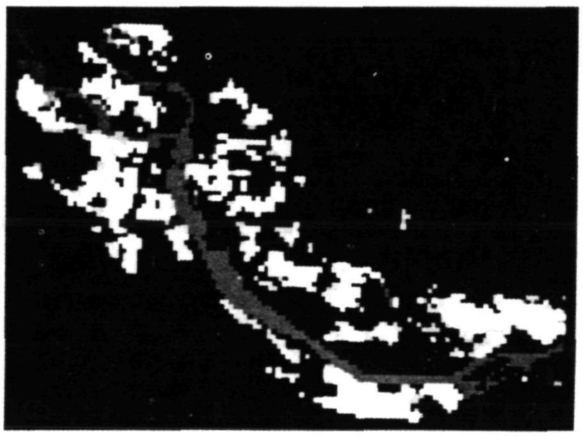

Fig. 4 : Classification results with M.L. Class 2 well recognized: white; class 2 not recognized: intermediate grey; class 1 well recognized: light grey (very close to white)

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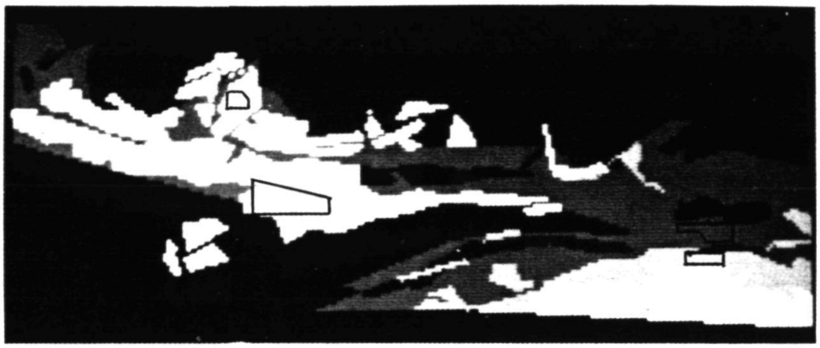

Fig. 5 : Ground truth for beeches and chestnuts. Beeches: white; chestnuts: light grey; meadows: dark grey; uncharacterized zones: black. Approx. scale 1:125,000

Fig. 6 : Classification results with M.L. July 3rd 1975; grey levels as in Fig.5

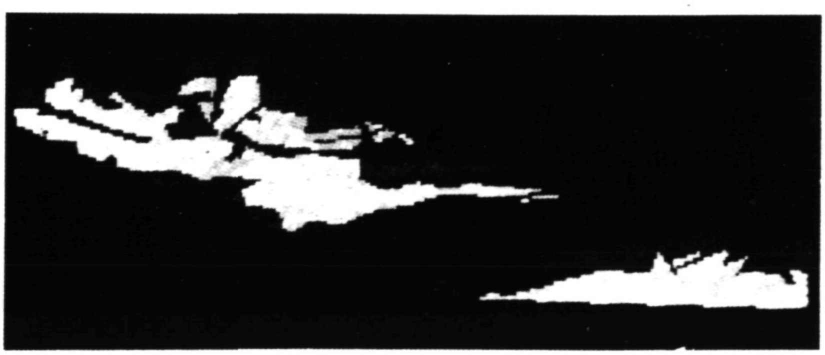

Fig. 7 : Detailed results for beeches. Beeches well recognized: white; beeches not recognized: light grey; "others" misclassified as beeches: dark grey

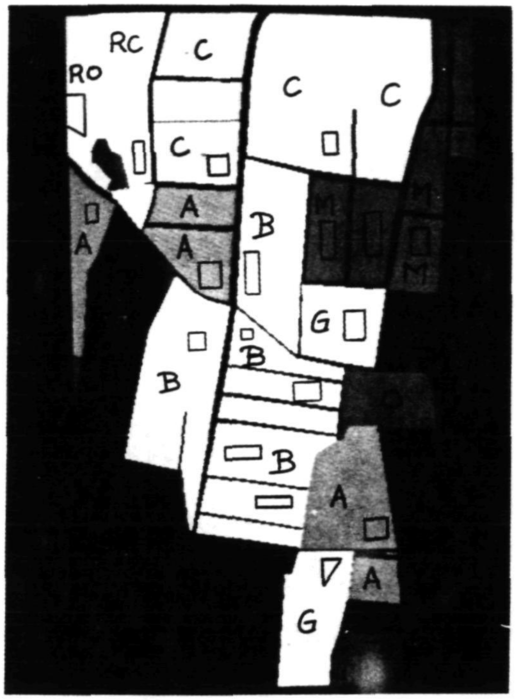

Fig. 8 : Ground truth for rice varieties. G, B, A, C, RC and RO are rice varieties (see section 5.1); MR: wet meadows; O: others. Approx. scale 1:23,000

Fig. 9 : Classification results with M.L. after atmospheric correction and feature selection from 8 to 5 dimensions. Grey levels as in Fig.8

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