MAPPING OF VEGETATION AND EVAPOTRANSPIRATION IN THE RÍO TUNUYÀN IRRIGATION SCHEME, MENDOZA, ARGENTINA, USING A SATELLITE IMAGE

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CONTENTS

1. INTRODUCTION

In February 1988 NEDECO, ICW, ILRI and INCYTH* started coopera-
tion in a project on irrigation water management. It resulted
from earlier cooperations between IILA* and INCYTH (1977-1982)
and ICW and INCYTH, both involving irrigation water management
(MENENTI et al., 1982; MENENTI et al., 1985) and since 1984
remote sensing. Its objective is to develop a method to evaluate
and optimize the water distribution of large irrigation schemes
using satellite remote sensing and numerical modelling. To quan-
tify the performance of irrigation water management three indices
were defined (MENENTI, 1988):

1. The amount of water applied to one hectare of irrigated land
   within a specific reference unit, divided by the amount of
   water applied to one hectare of irrigated land in the larger
   unit of which the reference unit is a part.
2. The amount of water that is needed in a specific reference
   unit to maintain potential evapotranspiration, divided by the
   amount that is actually applied to that unit.
3. The difference in actual evapotranspiration in situations with
   and without irrigation within a unit, divided by the amount
   applied to it.

Based on the values of these indices the water distribution schedule
can be optimized.

Considering the availability of data at the INCYTH, the Rio Tunuyan
Irrigation Scheme (in the province of Mendoza, Argentina), was
chosen to serve as a study area. The evaluation and optimization would
have to be performed for the Viejo Retamo, a secondary canal within
that project.

This report deals with an investigation that was done to determine
the second index. For this index it is necessary to have information
about the vegetation in the Viejo Retamo. This information can be
acquired with satellite images and field information.

The purpose of the investigation is to use a satellite image to make a
map of the different crops in the area. If this is not possible, a map
with groups of crops with a similar evapotranspiration behaviour

will be sufficient. Beside this purpose, the investigation is done to try out the different methods to form classes and execute a classification, and to judge the results for this specific area.

In chapter 2 an impression is given of the study area and the groundtruth that formed a basis for the invextigation. In chapter 3 the used methods are described. The results are compared with each other in chapter 4. Chapter 5 handles the Kc-values that are given to the formed vegetation classes. After this, the conclusions are given in chapter 6 where also the final results are presented. At last some recommendations for further investigations are given in chapter 7.

* NEDECO: Association of enginering companies for development, the Netherlands.
  ICW: Institute for Land and Water Management Research, Wageningen, the Netherlands
  ILRI: Institute for Land Reclamation and Improvement, Wageningen, the Netherlands
  INCYTH: Instituto Nacional de Ciencias Y Technicas Hidricas, Mendoza, Argentina
  IILA: Instituto Italo-Latino Americano Rome, Italy

2. STARTING POINTS AND DESCRIPTION OF THE STUDY AREA

2.1. Description of the study area

The Rio Tunuyan Irrigation Scheme is located in the province of Mendoza, Argentina, just east of the Andes at an elevation of 650 m a.s.l.. It is an arid region with an average yearly rainfall of about 210 mm. The surface is almost flat with a slight inclination towards the east. The area irrigated by the Rio Tunuyan Irrigation Scheme is about 70,000 ha, the area of influence of the Viejo Retamo secondary canal is about 5000 ha. (See figure 2.1 for the location of the Viejo Retamo.)

2.2. Groundtruth

For this investigation the TM-image of January is used. The groundtruth data were collected in april 1988. The vegetation in four tertiary units (Gonzales, Alcarez, Orrego and Day) is mapped for each field (see annex). In the same month an elaborate description is made of the vegetation on 11 fields, in which the crop variety, the groundcover, the percentage dead plants, and information about the undergrowing weeds are presented (table 5.1).

Referring to the groundtruth the following crops appear most in the Viejo Retamo area:

VINICULTURE

Parrales (P):   Italian way of vine production, where the plants in the different rows are connected at a certain height, varying from 30 cm to 2 m (see figure 2.2), which causes a high groundcover percentage.

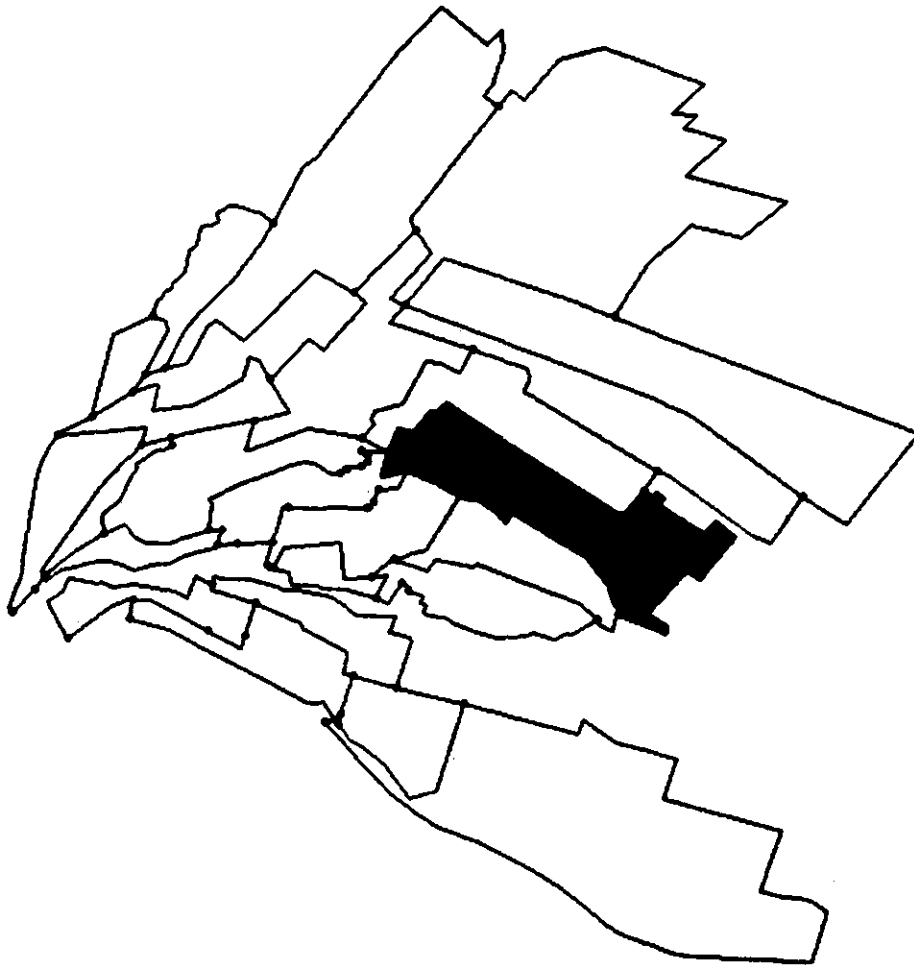Vinedo (V):   Vine production in rows (see figure 2.2).

FIGURE 2.1 Map of Rio Tunuyan Irrigation Scheme showing boundaries
of the command areas of the secondary units; Viejo
Retamo secondary unit is shown in black.

Viñedo   Parral

FIGURE 2.2 Different ways of vine production.

Espalderos (E): A way of vine production between Vinedo and
Parral.

ORCHARDS

Pears   - Spanish name: Perales (Pe)
Quinces   - Spanish name: Membrilleros (M)
Peaches   - Spanish name: Durazneros (D)
Apricots - Spanish name: Damascos (Da)

MIXTURES

On some fields both grapes and fruits are grown. The
fruit-trees stand in the vine-rows as well as between the rows. The
most usual combinations are vinedo with pear (VcPe) and vinedo with
peach (VcD).

OLIVES

There are hardly any oliveyards in this part of the Rio Tunuyan
Irrigation Scheme. This crop is therefore not included in the
formation of classes.

FALLOW

In the area a great number of fields is not irrigated. Of these fields
part is bare, to be used for the cultivation of onions and garlic in
wintertime Another part is covered with weeds (Spanish name: Inculto
(I)).

Some vineyards and orchards are abandoned so that the plants are
totally or partially dried (Spanish name: Abandonado (Ab)). Often
there is a lot of weed on these fields.

NOT CULTIVATED LANDS

At the borders of the secondary unit there are areas that are not
cultivated. These areas are covered with bushes with a high drought-
resistance. Because these areas are located immediately outside the

tertiary units with groundtruth, this class of vegetation is
introduced in the final map of the vegetation in, and around the Viejo
Retamo.

2.3 The image processing system

At the ICW the ERDAS automatic image processing system is used. The
hardware consists of a PC, a terminal, a tape-unit, a colorgraphic
monitor, a printer and a color plotter. In the ERDAS software there
are modules for p.a. geometric correction of the image, the
classification of an image and visualization of the results. The
results of different classification processes can also be compared
with each other.

For this report it is not necessary to give an extensive summary of
the possibilities of the ERDAS system. For further information about the
ERDAS, see the ERDAS-manual.

3. THE FORMATION OF CLASSES AND CLASSIFICATION

3.1. Processing of the groundtruth

To use the groundtruth in satellite image processing it is necessary
to locate this information in the image.The fields with a known crop
are therefore indicated by polygons. For a good interpretation of the
groundtruth it is important that the area inside the polygon is
homogeneous. The pixels at the borders of the fields, which are often
mixed pixels, should not be included in the polygon. The standard
deviation in all bands of reflection is a measure for the homogeneity
of the polygon. For this investigation the polygon is considered
homogeneous when the maximum standard deviation in the less important
bands (1,2,6,7) is no more than 8 digital units. For the important
bands for vegetation, (bands 3,4 and 5) this limit is 5 units. The
mean standard deviation cannot be more than 3 units. Another
restriction for the polygons is the size of the fields. The spatial
resolution of the TM-image is 28.5 x 28.5 m. This means that the
fields often have to be more than 75 x 75 m (3 x 3 pixels) to contain
one pixel that is not a mixed pixel. Only with these pixels the
polygons can be homogeneous. Polygons of very few pixels cannot be
drawn. Therefore the miminum size of a useful polygon is about 6
pixels. With these restrictions, polygons could be indicated.
for only 80 fields in the image.

3.2. The distribution of the vegetation according to the
 groundtruth

Normally in a vegetation classification, the fields with the same
crop are supposed to be alike, so that they form one class. Because of
the number of vegetation types in the area, compared with the relative
small number of polygons, some vegetation types that have a lot in
common are put together in one group. The mixtures of vine and fruit
are put together in one class: Vinedo with fruit (VcF). The apricots
(damascos) have a clearly different spectral signature than the other
fruits and form therefore a separate class: Apricots (Da). The pears,
quinces and peaches are put in the class fruit (F). Because it is

difficult to see the difference between espalderos and parrales in the
field, these two groups are put together in a class: Parral (P). The
difference between the abandoned (Ab) vineyards and orchards and the
fallow (I) fields with weeds is sometimes very small. The classes are
not put together because the difference between fields with and
without weeds is too big. There are two different classes with
unirrigated fields. When these classes contain abandoned fields as
well as fallow fields, this is not seen as a wrong interpretation of
the vegetation.

Finally there are some polygons where values make clear that the soil
use changed between the moment the image was taken (January 1986) and
when the groundtruth was gathered (April 1988). Some fields p.a. can
be seen on the picture as covered with a good growing crop, while in
the groundtruth these fields are mentioned as abandoned. For this
reason 8 polygons were eliminated. To compare the results of the
different classifications with the groundtruth a reference
vegetation map is made of the 72 polygons that are left. Every
polygon received a value that corresponds with a certain crop. This
map is given in figure 3.1.

After the formation of classes the TM-image is classified. In this
investigation only the pixels in the polygons were used for the
classification and not the entire TM-image. Only these parts can be
compared well with the map in figure 3.1.

To assign the pixels in the image to the formed classes, a decision
rule has to be chosen. Available are the maximum likelyhood, the
minimum distance to mean and the Mahanobis decision rule. All three
methods are applied to compare the results with each other, and to
choose the best. The results of the classifications of the image are
described in chapter 4. At this point it should be noted that the
maximum likelyhood turned out to be the best decision rule for this
area. This one is used for the classification of the image with all
the classes that are formed by the methods in the following
paragraphs. When the image was classified with the crop classes from
the groundtruth, the classified images showed that there is a lot of
difference between the groundtruth and the resulting classified

FIGURE 3.1 Distribution of the vegetation over the polygons used as
groundtruth.
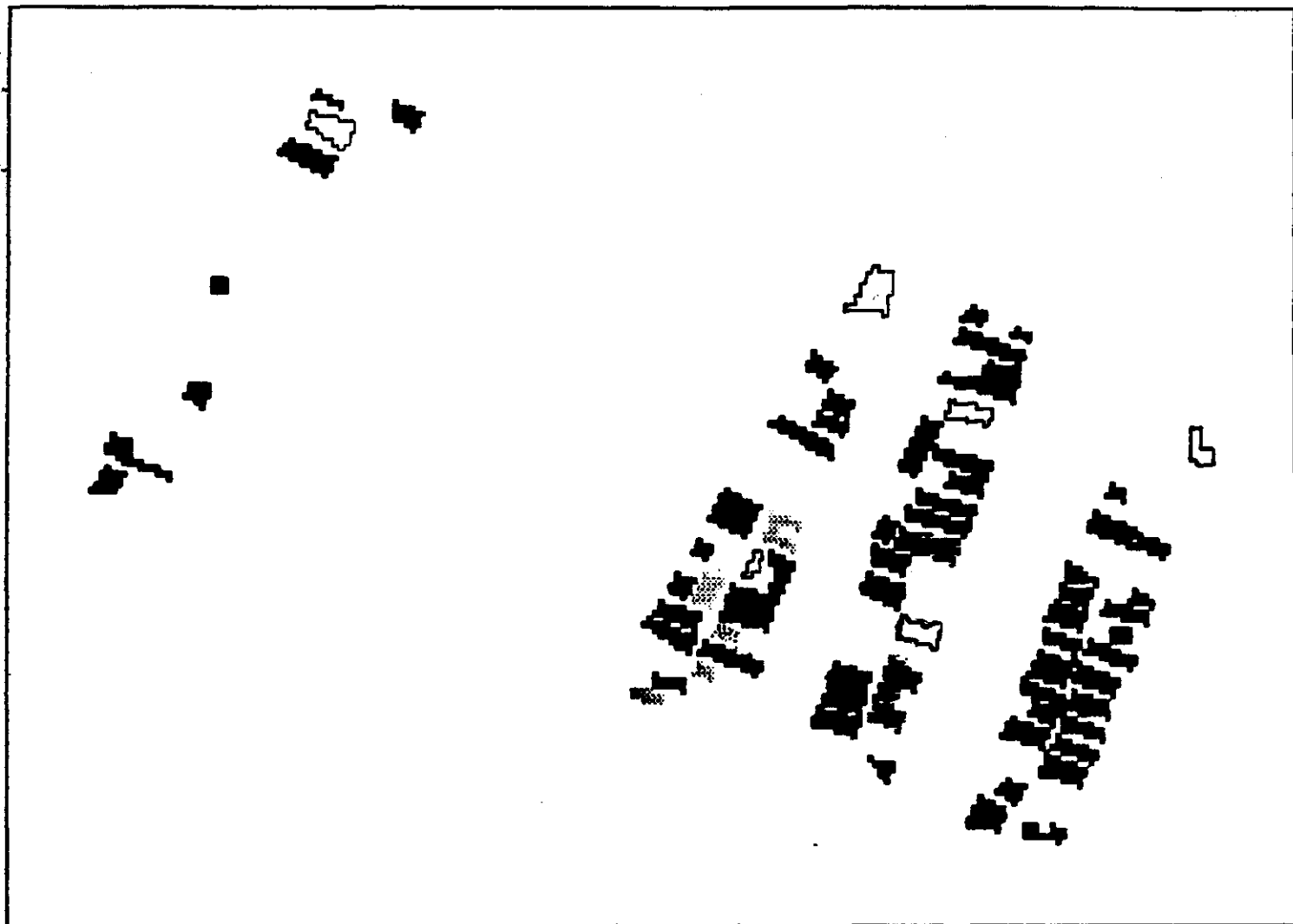
Vinedo   Fruittrees   Fallow

Parral and Espaldero   Apricottrees   Abandoned

Vinedo with fruittrees

images. There are two reasons for this difference. Firstly the differences between spectral signatures of the crops are very small, so that they are easily mixed up. There are only perennial woody crops in the area. Beside this, the differences caused by the distance between the rows, the height of the crop, the variety of the crop and the undergrowth, are very big. An unequivocal relation between spectral signature and crop cannot be found for this area. For this reasons the research is no longer directed at the classification of individual crops. It should be tried to form crop classes that are separable and contain one or more crops showing a similar behaviour concerning evapotranspiration.

3.3. Manual formation of classes based on digital numbers

To get an idea about the occuring spectral reflectances, tables are made of the average digital values in the seven bands for each polygon. Using these tables groups of polygons with similar reflections are formed. Not only similarity in the very high or low values is important, but also in the combination of values in the different bands has to be considered. 57 polygons are used for the identification of 9 classes.The other polygons were hard to put in one of the classes with this qualitative method.

An important drawback of the formation of classes in this way is the influence of the investigator on the final results. This means that results can also not be reproduced, so that the method is not recommended.

3.4. Formation of classes with a correlation matrix

The second formation of classes is based on a matrix with the correlation between polygons. With this matrix the classes are formed in a more objective way than with the former method. To make such a matrix, the distance in the n-dimensional space between a pixel and the nearest polygon average is calculated for the combination of bands with one of the decision rules. This distance can be the distance from the pixel to the average of the polygon it belongs to. It can also be the distance to the average of another polygon. The latter can happen because the pixel is rather different from the other pixels in the polygon, or because the average of another polygon is more or less equal to the own polygon average. When a pixel is closer to the average of another polygon than its own, this can be an indication for

similarity between these polygons. Only when there are more pixels correlated with the other polygon it can be said that the polygons are similar.

The result of the calculations is a matrix (in this case 72 x 72) in which is noted for every polygon how many pixels belong to other polygons and to which polygons. The minimum distance decision rule is used for this matrix because the number of pixels correlated with other polygons is the largest here. To analyse the information in the matrix, one can regard the columns as well as the rows. In the columns one can see to which polygon the pixels of a polygon are assigned (way A: columns, figure 3.2). In the rows is noted in which polygons the pixels are located that have a correlation with the average of a certain polygon (way B: rows, figure 3.2). These two methods give different information.

A: columns

In homogeneous polygons all pixels are close to their own polygon average. Even though these polygons contain the best information for a classification they do not give information for the formation of classes. According to the columns there is no correlation with other polygons. In less homogeneous polygons more pixels are correlated with the averages of other polygons. For these polygons there are tables made, in which is noted if there is much (more pixels), little (one pixel) or no correlation (no pixels) between the polygons. With these tables some classes are formed. A disadvantage of this method, in which the information in the columns is most important, is that the polygons that contain the best information for classifications are not used to make the classes.

B: rows

Looking at the rows instead of the columns, the results are better. The amount of times a certain average is the nearest to pixels of other polygons is counted. An average which is very often the nearest for the pixels is supposed to be located between the other polygons in the n-dimensional space. The polygon averages that are hardly ever the nearest, are supposed to be located further away from the other polygons. In this way there were 6 center-polygons (at least for pixels from 10 other polygons this one was the nearest), and 20 side-polygons (less than 3 polygons had pixels belonging to this average). The information in the rows as well as in the columns were tabeled for the center-polygons. With the correlations in these

FIGURE 3.2 Ways for the formation of classes with a correlation
matrix
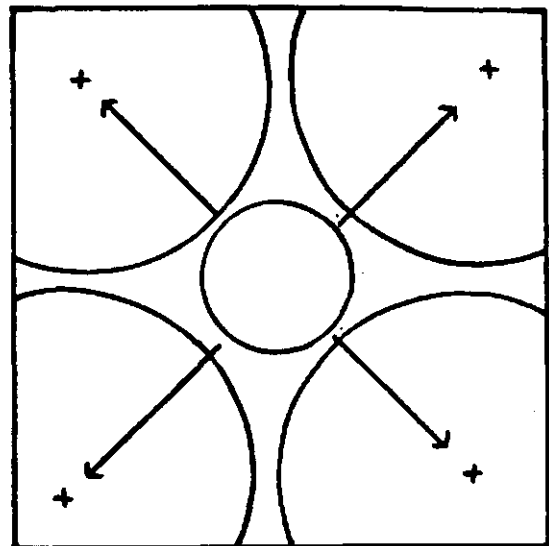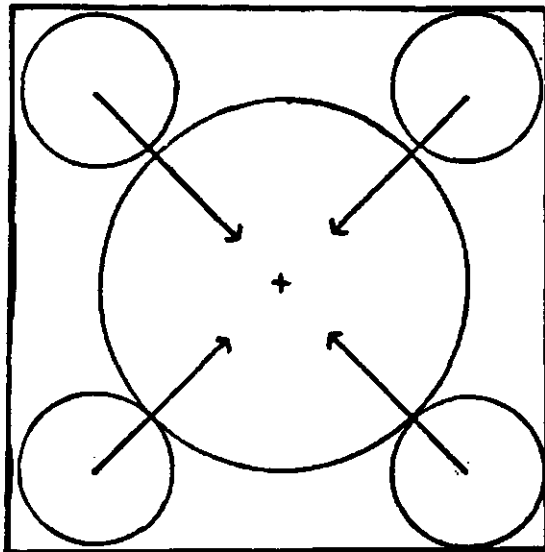
A: Columns
What pixels belong
to the average of
this polygon.

B: Rows
To what average
belongs this pixel.

x   polygon average

O   pixel
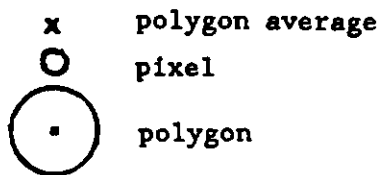
     polygon

tables a first attempt was made to make a two-dimentional figure which
gives an idea of the location of the polygons and the formed classes
as in figure 3.3. With the side-polygons this figure is completed.

With the classes as identified looking at the rows, the TM-image is
classified.

A disadvantage of the method with the correlation matrix is that the
values of all the pixels are used for the formation of classes. This
means that there is no unused groundthruth left to check this

FIGURE3.3 2-dimentional diagram of the location of classes as
determined with a correlation matrix
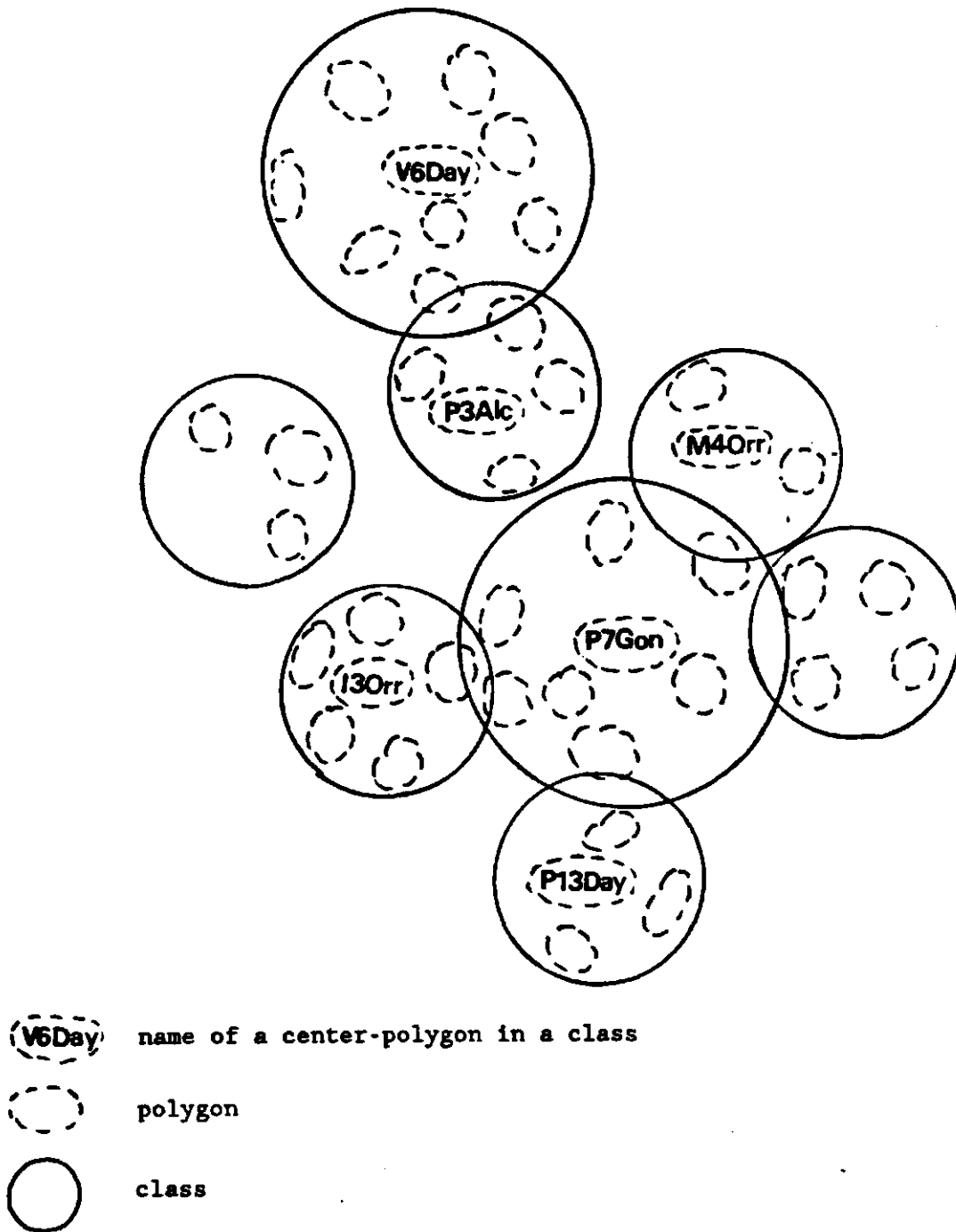
class-formation. With most of the other methods the check is possible because then the classes are formed with only the average values for each polygon. Another drawback is that the method is still not very objective.

3.5. Formation of classes using SPSS

In case there is no groundthruth or when separate crop-classes cannot be made with the available groundtruth, like in this case, classes are formed with a so called cluster-analysis. The given information is automatically divided into classes using a chosen decision rule.

The ERDAS software does not allow to follow the clustering process step by step. Therefore the statistical package SPSS is used to give a certain order to the available information. The result of such an ordening is a dendrogramm (figure 3.4 gives an example). The admission of the different elements is visible at all possible levels. This gives the user the possibility to choose which clustering level meets best with the chosen objectives.

- Formation of classes

In this case the averages for each band of all the polygons useful for analysis are entered as data in the SPSS cluster analysis. These averages are clustered with all the available decision rules. These are: The Ward-, centroid- and the single linkage decision rule. This is done with the averages of all the seven bands, and with only the averages of the four most important bands (3,4,5,6). The cluster analysis is also done with the results of a principal component analysis. The analysis based on the four most important bands offered the most useful results.

The dendrogram made with the single linkage method gave many classes with fallow fields and only one class with vegetation. For the purpose of the classification of vegetation this decisionrule is not useful. For the Ward decision rule the best results are expected at a clustering level with 7 classes. For the centroid decision rule the number of classes is 9.

- Classification

Because the SPSS is a statistical package and not an image processing package, it is not possible to work up a classified map using this package. The polygons of one cluster, as determined using SPSS are therefore put together in one class. With these classes the image classification was performed on the ERDAS system.

FIGURE 3.4 Example of a dendrogramm

name   Rescaled distance between the polygons
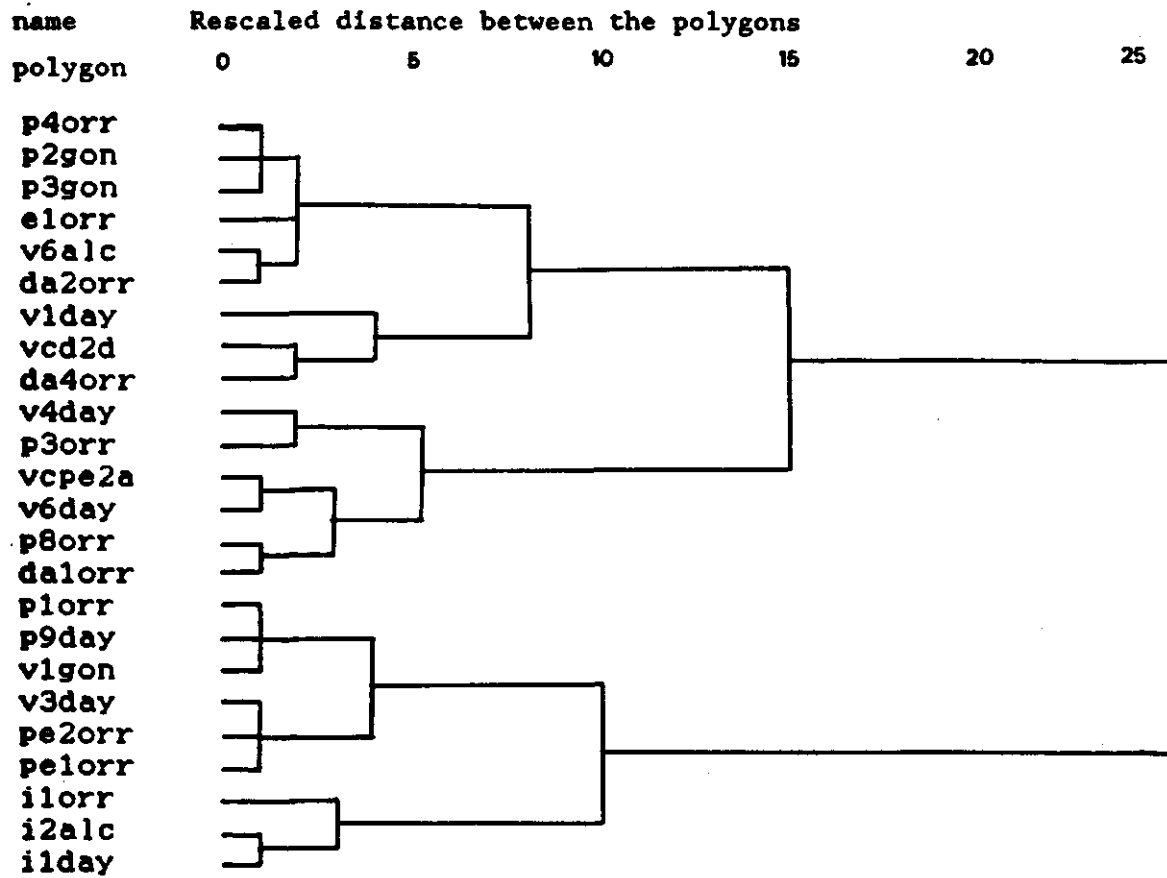
An occuring problem is that the decision rules of the ERDAS software are not the same as those used in SPSS. In paragraph 3.2 where the ERDAS decision rules were tested, the maximum likelyhood decision rule turned out to be the best, so this is used for the classification with the SPSS classes too. Even though the minimum distance decision rule looked a lot like the centroid, the results of the classification with this decision rule were of less quality.

3.6. The cluster analysis method of the ERDAS system

When a cluster analysis is done using the ERDAS software, the given information is directly worked up to a classified map. It is not possible to choose a clustering level and there is no way to see the results of the cluster analysis alone (Without the classification). The number of classes must be given beforehand. To find out the best number of classes, the formed classes have to be taken from the classified map. This reduces the reliability. It appeared that the clustering follows different paths for each given number of classes. When there is one class more on the SPSS system this means that one class has to split up. With the ERDAS software all classes change when one class more is required. There are no clear clustering levels.

Another negative point again is that all the information of the pixels is used. There is no information left to check the results. ⤫

The classification is done with 7,8,9 and 10 classes. The classification with 9 classes was best. The classification is compared with the other classifications in chapter 4.

4. RESULTS

4.1. Introduction

To classify a satellite image, classes have to be formed (class-formation). Next the pixels in the image have to be assigned to a certain class (classification). Each class is presented by a digital value in the classified image. The results of the class formation as well as the classification do not directly give an idea about the quality of the used methods. To test the methods, a few criteria are chosen. Some judge the class formations and others the classifications. In this chapter, an overview of these criteria is given, the results for each method follow. An evaluation table shows what methods are best to make classes and to classify an image in this specific study area.

4.2. Criteria for the formation of classes

1 The ellipse plot (two dimentional feature space plot)

A first impression of the discrimination between the classes of a class formation can be acquired with an ellipse plot. With the ERDAS system it is possible to make a graphic image of a class formation. An ellipse is drawn around the center of a class, the size of the ellipse depends on the chozen standard deviation. For the ellipses of figure 4.1 the standard deviation is one unit. A class formation that separates the classes well does not show overlap between the ellipses (figure 4.1).

Figure 4.1 shows clearly that the crop classes have much overlap.

The handmade classes with the reflectiontable, and the classes formed with the correlation matrix, show less overlap.The SPSS classes are all very well discriminated, in the bands 3,4 and 5 there is no overlap at all. The distance between the ellipses is bigger for the classes formed with the centroid method. The location of most classes

is more or less the same for all the used methods, except for the crop classes.

2 The homogeneity of the vegetation in each class

As mentioned before, with the available material and information of the study area it is not possible to discriminate the individual crops. Vineyards occur in every class except the classes with abandoned and fallow fields. In every class there are also fields with another crop. The share that one or two main crops take in a class, is a measure for the crop discrimination capability of the used method to form classes. The normalised frequencies of the different crops in every class are determinated and for the main crops written in table 4.1. For the various methods of class formation is noted how big the share of the main crops is in every class. The share of the first main crop varies from 41 to 60 %. For two main crops this value varies from 65 to 80 %. The method with the correlation matrix gives the best results.

4.3. Criteria for the classified image

1 Differences between formation of classes and the classified map

When a classification is good, a pixel that belongs to a certain class in reality, also gets the value of that class after classification of the image. In the ideal case this works for all the pixels in a polygon.

The value of most pixels in a polygon (after classification) can be given to all the pixels in the polygon, this to make the polygon homogeneous. The number of homogeneous polygons that have a different value on the image as it had to have according to the class formation, is a measure for the quality of the classification (and also of the class formation). The results are shown in table 4.2.
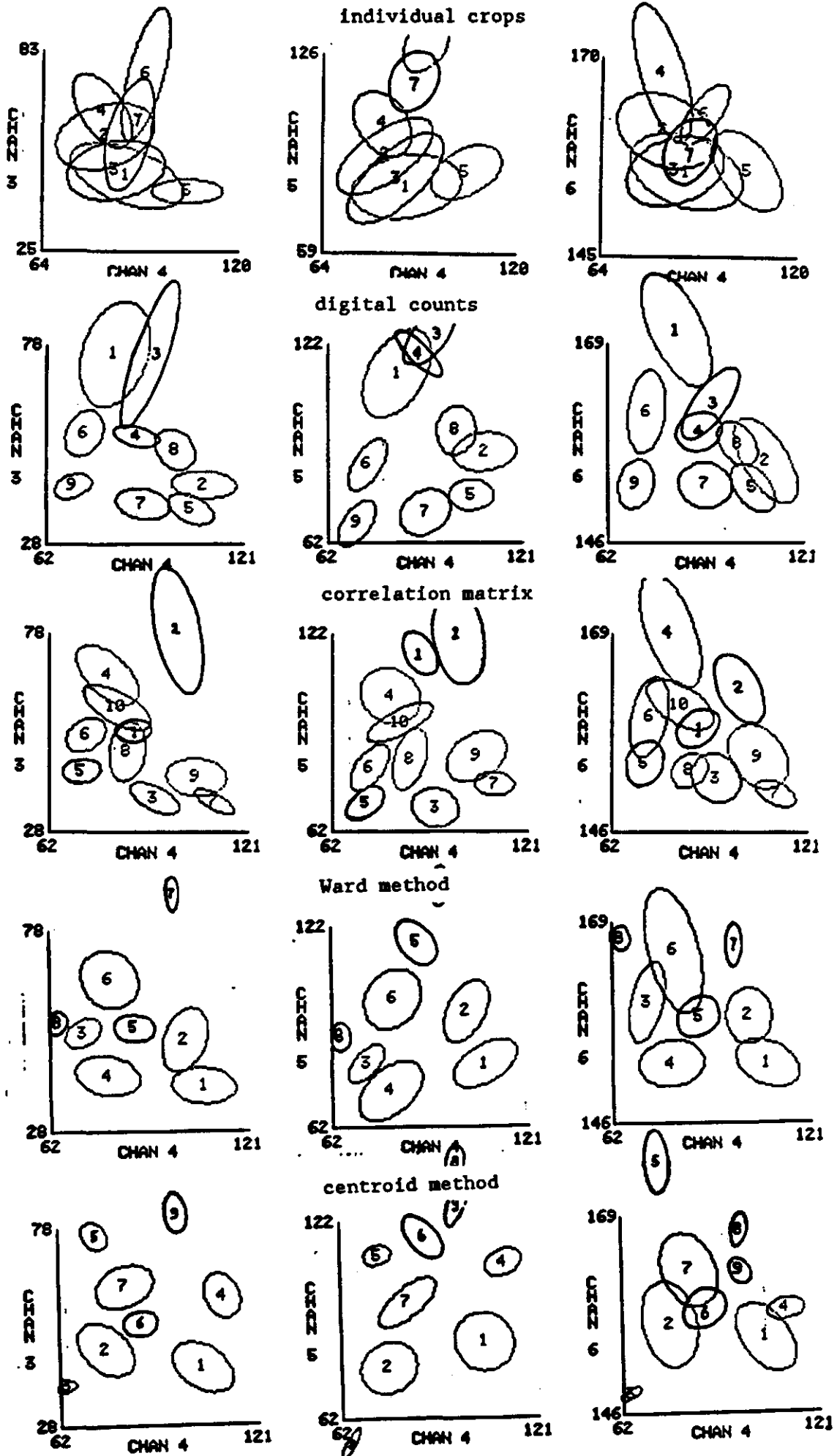
FIGURE 4.1 Ellipse plots

individual crops

digital counts

correlation matrix

Ward method

centroid method

TABLE 4.1 The homogeneity of the vegetation for each class.

1 class formation based on individual crops
2 class formation based on digital counts
3 class formation based on the correlation matrix
4 class formation with the Ward decision rule
5 class formation with the centroid decision rule
6 ERDAS cluster analysis

All classifications are performed with the maximum likelihood decision rule.

n: number of polygons per class
k: classnumber in the classification
G1: first main crop
%1: share of the first main crop in the class
G2: second main crop
%2: share of the two main crops in the class

1

k	n	G1	%1
1	28	P	100
2	13	V	100
3	8	VcF	100
4	7	F	100
5	5	Da	100
6	6	I	100
7	5	Ab	100

gemiddeld   100 %

2

k	n	G1	%1	G2	%2
5	8	P	43	Da	84
6	18	V	39	P	67
7	7	VcF	42	Da	76
8	8	VcF	41	F	64
9	7	VcF	49	V	78
1	11	F	53	I	80
2	4	Da	94	P	100
3	5	I	100	I	100
4	4	I	100	I	100

41 %   65 %

3

k	n	G1	%1	G2	%2
5	6	V	39	VcF	71
6	12	VcF	30	V	58
7	5	VcF	57	V	91
3	6	VcF	45	Da	80
4	8	F	83	V	92
9	4	F	56	P	100
8	13	Da	60	P	92
10	3	Da	62	V	87
1	6	I	100	I	100
2	10	I	69	V	87

60 %   80 %

4

k	n	G1	%1	G2	%2
4	13	VcF	47	P	67
2	9	VcF	34	Da	61
3	10	V	31	Da	59
6	14	F	56	V	82
1	12	Da	62	P	92
5	6	I	100	I	100
7	5	I	100	I	100

gem.   55 %   77 %

5

k	n	G1	%1	G2	%2
3	1	P	100	P	100
2	22	VcF	35	V	57
4	3	VcF	50	V	83
5	2	F	100	F	100
7	12	F	38	V	75
1	18	Da	55	P	82
6	6	I	100	I	100
8	3	I	100	I	100
9	2	I	100	I	100

54 %   75 %

6

k	n	G1	%1	G2	%2
8	6	VcF	53	V	86
7	9	VcF	34	Da	59
6	11	F	37	P	63
2	11	F	36	V	70
9	2	F	100	F	100
1	20	Da	49	P	75
4	4	I	60	F	85
5	6	I	100	I	100
3	3	I	100	I	100

52 %   74 %

TABLE 4.2 Difference between the formation of classes and the
classified map.

Classification methods: A Maximum likelihood

B Minimum distance to mean

C Mahanobis distance

method	total number of polygons	wrong polygons	% wrong polygons
Crops			
A	72	17	24
B	72	40	56
C	72	21	29
Digital	57	0	0
Correlation	72	6	8
Ward	70	3	4
Centroid	70	1	1
Cluster	72	?	?

From this table it appears that the minimum distance decision rule
leads to ~~bad~~ POOR results. More than half the number of fields are
classified incorrectly. The best classification method is the maximum
likelihood.

For the class formation methods, it is obvious that the formation
based on crops has less interesting results as the others. By the
class formation based on digital counts, there are no polygons
incorrectly interpreted. This is easilly understood, because the
classes are made with only the polygons that fitted very well in a
class. The more difficult polygons are not used in this method. In
other class formations, these more difficult polygons are the ones
that are classified erroneously. This does not have to be a great
number of polygons as can be seen for the centroid method.

2 Number of pixels in the wrong class after classification

A classified polygon can be made homogeneous by giving the class-
value of the mayority of the pixels to all pixels in the polygon. The

number of pixels that has to be changed in order to make the polygons homogeneous, is a measure for the quality of the classification. A part of these pixels will always have a different value than the rest of the pixels in the polygon, because the circumstances in the field are different at that particular place. Another part will have another value, depending on the used classformation and classification methods. The more of this last type of pixels, the less trustworthy the methods. The number is determined by making an automatic overlay of the classified image and the homogeneous image. The results are in table 4.3.

TABLE 4.3 Number of pixels in the wrong classes after classification

method	total number of pixels	number of changed pixels	% changed pixels
Crops			
A	1730	586	34
B	1730	1016	59
C	1730	525	30
Digital	1730	248	14
Correlation	1730	223	13
Ward	1730	154	9
Centroid	1730	145	8
Cluster	1730	253	15

The results of this criterium are more or less the same as for the former criterium. The minimum distance is not such a good method. Mahanobis and maximum likelihood are much better. The classification on individual crops does not give good results, the other methods, in particular the Ward- and centroid method do. The percentages are much closer together than with the former criterium. It is evident that the manual method based on digital counts is not better than the other methods on the basis of this criterium. Obviously the number of wrongly classified pixels is also large for this method, but not large enough to give another polygon value after the homogenisation of the polygon.

With criterium 4 all incorrectly classified pixels are counted. With
criterium 3 on the contrary only the polygons where most pixels have a
wrong value are counted. These pixels are not counted with criterium 4.
The combination of these two criteria gives an complete image of the
number of wrongly classified pixels.

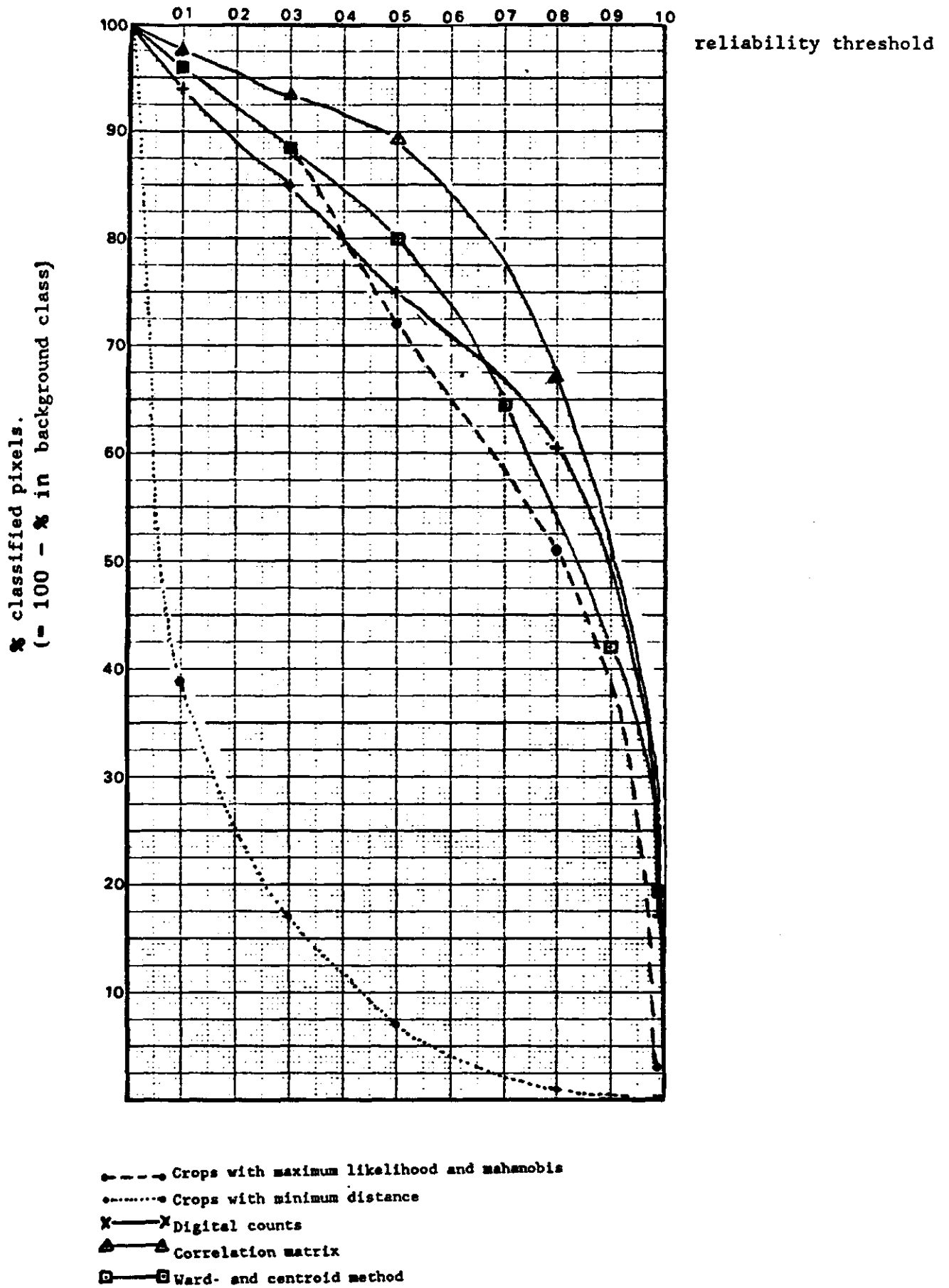## 5 The reliability of the classification

With the ERDAS software it is possible to test a classification on its relia-
bility. With the maximum likelihood decision rule all pixels of the
image are put in a class, even though they do not fit well in any of
them. In other words no background class is made automatically (Background
class - unclassified pixels).

By taking a reliability threshold, a background class is made. The
higher the threshold, the more pixels go to the background class. If
from a classified image most pixels end up in the background with a
low threshold already, the used methods to make classes and to
classify the image are not too reliable. When the pixels stay in their
classes even though the threshold is high, the class formation and
classification methods are good. The number of pixels in the
background class are determined for a serie of threshold values for
all the different classification methods. The results are given in
figure 4.2.

In this figure it is apparent that the minimum distance to mean
decision rule is very strong. Only the pixels that have exactly the
average class value, do not end up in the background immediately,
the others all do. Because the original image is classified for all
class formation methods with the maximum likelihood decision rule, the
differences in class formation methods can be seen. The figure shows
that these differences are not big.

The best results are given by the class formation with the corre-
lation matrix. Because all pixels are used in the class formation the
reliability seems good. To judge the quality of this method it is
necessary to test the results with some unused groundtruth, which is
not available in this case.

FIGURE 4.2 Reliability of the classification

reliability threshold

% classified pixels.
(= 100 - % in background class)

•－ －－• Crops with maximum likelihood and mahanobis

•－······• Crops with minimum distance

✗————✗ Digital counts

▲————▲ Correlation matrix

▣————▣ Ward- and centroid method

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4.4. Evaluation

The evaluation of the used class formation- and classification methods are summarized in tabel 4.4.

The lack of information about the ERDAS clustering analysis is remarkable. This method gives no information about the class formation and classification. Therefore it is difficult to compare the method with the others. It is obvious that the minimum distance to mean classification method in combination with crop classes gives very bad results. The other classification methods give a better result with the same classes, but these results with crop classes are also not good. So the class formation based on crop classes is no good method for this region.

The manual formation of classes, based on digital counts and with the correlation matrix are fair. The method with the correlation matrix has a good crop homogeneity and reliability. It is nevertheless impossible to evaluate this method well with the mentioned criteria, because all information has been used to indicate the classes.

The discrimination of classes (ellipse plots) is not good. The problem with both methods remains the impossibility to reproduce the results, and the great influence of the analyst.

The best method is the cluster analysis based on SPSS. The results of both methods (centroid and Ward) have much in common. The discrimination of the classes is a little better for the centroid method and the Ward method has a few more incorrectly classified polygons (Ward 4, centroid 1). The percentage wrong classified pixels also is somewhat larger (Ward 9 %, centroid 8 %). But the crop homogeneity of the Ward method is better (77 % Ward, 75 % centroid). All differences are very small. The most important difference is the number of classes. This is 9 for the centroid method (of which 5 classes with less than 5 % of the pixles) and 7 for the Ward method.

The final classification of the total Viejo Retamo is performed with

the Ward method. The quality of this method is the same as the centroid method, but the number of classes is smaller.

TABLE 4.4 Evaluation of the used methods

code	class formation	classification
A	individual crops	Maximum likelihood
B	individual crops	Minimum distance
C	individual crops	Mahanobis distance
DW	Digital counts	Maximum likelihood
CM	Correlation matrix	Maximum likelihood
WA	Ward method	Maximum likelihood
CE	Centroid method	Maximum likelihood
CL	IPS clusters	Maximum likelihood

Judgement: ++ very good compared with the other methods
             + good compared with the other methods
             o intermediate compared with the other methods
             - bad compared with the other methods
             -- very bad compared with the other methods

criterium	A	B	C	DW	CM	WA	CE	CL
1 Ellipse-plot	--	--	--	o	o	+	+	?
2 Crop homogeneity	++			o	++	+	+	+
3 Incorrect polygons	-	--	-	++	o	+	++	?
4 Incorrect pixels	o	--	o	o	o	+	+	o
5 Reliability	o	--	o	o	++	+	+	?

4.5. Conclusion

To make a map that gives insight in the distribution of the vegetation in the irrigated area of the Viejo Retamo, with the available

satellite information and groundtruth, according to the results with the mentioned criteria, the formation of classes with the SPSS Ward method and classification with the Maximum likelihood decision rule is the most workable.

5. THE EVAPOTRANSPIRATION OF CROPS

5.1. The Kc-values for each class in January

It is not right to say that the Kc-value of the most occuring crop in one class is representative for all fields in that class, because this main-crop is present only on approximately half of the fields in that class, and the Kc-value of this main crop can vary a lot. It is better to make an estimation of the Kc-value of a class in another way.

In this chapter, a method is described to estimate the Kc-value of each class with the use of the elaborate groundtruth (table 5.1).

TABLE 5.1 Elaborate groundtruth in the research area d.d.5-4-1988

poly-gon	crop	variety	ground cover	dried plants	undergrowth cover	undergrowth height
VcDday	vinedo	criolla	18 %	10 %	30%	5 cm
V1day	vinedo	criolla	18 %	5 %	25 %	5 cm
V3day	vinedo	mezcla	12 %	25 %	50 %	30 cm
V4day	vinedo	mezcla	13 %	5 %	< 30 %	5 cm
V6day	vinedo	mezcla	12 %	20 %	> 70 %	5 cm
Pe1orr	peral	williams	20 %	20 %	> 70 %	20 cm
Pe2orr	peral	williams	20 %	5 %	< 30 %	0 cm
Da2orr	damasco	tilton	60 %	0 %	< 30 %	20 cm
P8orr	parral	criolla	25 %	0 %	< 30 %	0 cm
P4orr	parral	criolla	25 %	0 %	< 30 %	0 cm
I1orr	-	-	-	-	> 70 %	50 cm
Da1orr	damasco	tilton	38 %	0 %	< 30 %	-
D1orr	durazno	?	32 %	0 %	< 30 %	-

From a research on evapotranspiration in Argentina the monthly average Kc-values for each crop are known (table 5.2A and figure 5.1).

TABLE 5.2A Kc values of crops according to the INCYTH

Crop	Sept	Okt	Nov	Dec	Jan	Feb	Mar	Apr	annual
Vinedo	0.37	0.52	0.64	0.71	0.74	0.73	0.68	0.59	0.62
Parral	0.37	0.71	0.79	0.89	0.93	0.93	0.83	0.64	0.90
Peral/membr	0.63	0.78	0.89	0.94	0.94	0.89	0.79	0.64	0.81
Durasno/dam	0.74	0.89	0.99	1.03	1.02	0.94	0.82	0.65	0.88

TABLE 5.2B Kc values of crops according to the FAO

Crop	Sept	Okt	Nov	Dec	Jan	Feb	Mar	Apr	May
Parral	-	0.45	0.60	0.70	0.70	0.70	0.70	0.60	0.35
Frutales +	0.85	0.95	1.05	1.15	1.15	1.15	1.10	0.90	0.85
Frutales -	0.50	0.70	0.85	0.90	0.90	0.90	0.80	0.75	0.65

CHAMBOULEYRON 1978 and ORIOLANI and DEVIGE 1978 write that the Kc-value, especially for grapes can vary a lot. The INCYTH gives for grapes, an annual value between 0.42 and 0.90 depending on the variety. In January these values are higher. The variation is caused mainly by the variety of the grapes, the groundcover (row distance) and undergrowth. It is therefore not realistic to give all fields with one crop the same Kc-value.

With this literature, the information of the INCYTH and the evapotranspiration values as used by the FAO (table 5.2B), where a

time (months)
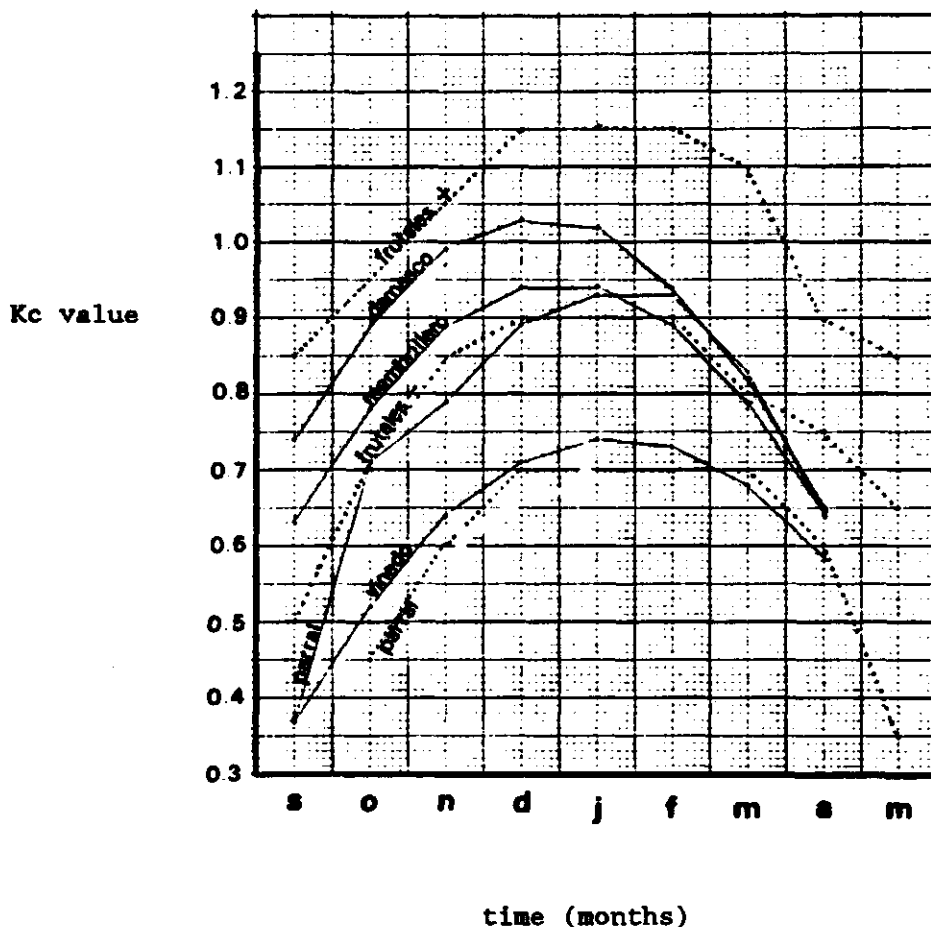
FIGURE 5.1 The course of the Kc-value during the growing season

    _____ Values of the INCYTH

    ...... Values of the FAO

    +   With undergrowth

    -   Without undergrowth

clear distinction is made between fields with and without undergrowth, the following assumptions are made:

Assumptions for the groundcover:

- For fruittrees the Kc-value is determinated for a groundcover of 70 %. When the groundcover of the field is less than 70 % the Kc-value is lower.

groundcover:	70 %	50 %	20 %
Kc-value:	1.00 x Kc	0.95 x Kc	0.85 x Kc

- For grapes, the Kc-value is determinated for 35 % groundcover.
  Similarly for fruittrees, this value decreases with the
  groundcover.

groundcover:	35 %	25 %	10 %
Kc-value:	1.00 x Kc	0.95 x Kc	0.85 x Kc

- Before the correction for groundcover can be done the percen-
  tage dry plants has to be considered. The total groundcover is
  reduced with the percentage dry and dead plants.

Assumptions for the variety of the crop:

- Only for grapes is there a clear difference between the varie-
  ties The occuring varieties of fruittrees do not have a different
  evapotranspiration pattern.
- The Kc-value of the most evapotranspirating type of grapes
  (criolla) 0.95 (at 35 % groundcover) in January. For the least
  evapotranspirating kind this is 0.70.

Assumptions for the undergrowth:

- The FAO uses for fruittrees with or without undergrowth a
  difference in Kc-value of 0.25. For the fruit trees, the mixed
  crops and grapes this is used as the traject over which the
  Kc-value can variate. Because the time-lag between the moment
  the image was taken and the gathering of the groundtruth is
  large, the information in the elaborate groundtruth about the
  undergrowth can not be used.

With these assumptions the Kc-value is determinated for the fields
where elaborate groundtruth is taken. For the classes to which these
polygons belong an estimation of the Kc-value is made. Where the
information is insufficient or where there are contradictions in the
information, the location of the Ward classes in the ellipse plot is
considered to make the estimation. The contradictions in the
information are supposed to be caused by the timelag between the
moment the picture is taken and the groundtruth is gathered.

The estimated Kc-values for the classes are mentioned in Table 5.3.
These values are given to the Ward classes on the classified image of
the entire Viejo Retamo.

TABLE 5.3 Kc-values for the with the Ward method formed classes

class	1	2	3	4	5	6	7
Kc-value	1.02	0.92	0.70	0.78	fallow	0.60	fallow

5.2. The Kc-values throughout the year

If the FAO data for evapotranspiration are used, the extrapolation to the other months is no problem. In figure 5.1 the Kc-lines for the different crops are parallel. For every calculated January value, a line can be drawn between the existing lines on which the Kc-values for a class for every month is shown.

The information of the INCYTH shows another picture. Here the grapes have their maximum evapotranspiration somewhat later than the fruittrees. The curves of the different crops are not parallel. Based on the information of the INCYTH it is difficult to give reliable Kc-values througout the year. To determinate these values better, it will be necesarry to use other satelite images p.a. of spring (september/october). At this time the difference in Kc-values of the crops is the clearest.

6. CONCLUSIONS AND FINAL RESULT

6.1. Conclusions

- Conclusions for the area

It turns out to be very difficult to discriminate the crops in the study area, with only one satellite image. Reasons are the great differences between the fields with the same crop, caused by variety, planting distance, undergrowth ect. On the other hand the problem is caused by the similarity of the different crops (all perennial and woody). The small scaled character of this part of the irrigation scheme causes that a great deal of the groundtruth cannot be used. At small fields the influence of de mixed pixels is big. Fields of 100 x 100 m often give bad information for this reason.

- Conclusions for the class formation and classification methods

First it has to be said that not all the possibilities to make classes or to classify an image have been tried out. Multitemporal methods and the TVI are not used. The principal component analysis gave poor results, but the method has not been well explored.

From the used methods the formation of classes with the SPSS Ward method, followed by a classification of the image with the maximum likelihood decision rule gave the best results. The classes are well discriminated, and the crop homogeneity is acceptable (77 % exists of two crop types).

Comparing the results of this classification with former research on the distribution of fields with and without irrigation (VISSER 1988), the Ward classification gives an underestimation of the percentage of not irrigated land. A reason for this can be that the young orchards, that look a lot like bare ground, are put in the class with fruittrees. Bare ground with little weed can be put in this class too, so that the total area fallow is less in the classification than in reality.

- Conclusions for the evapotranspiration

Because all the formed classes contain more than one crop, it is not
advisable to give the class the Kc-value of the most occuring crop. In
chapter 5 a method is discussed to make a reasonable estimation of the
Kc-factor for each class. The importance of the detailed groundtruth
is quite large using this method. Therefore it is advisable for a study
area like the Viejo Retamo, to collect this kind of information on
some representative fields. And it is important that this information
is gathered at the same time as the TM-image is taken. The
groundcover and the variety of the crop were the most important
factors in this elaborate groundtruth.

It was a negative point that there was hardly information about the
evapotranspiration in mixed cultures. The reliability of the Kc-values
for classes with many polygons with mixed crops was less because of
this.

The estimation of the Kc-values in other months was possible with the
FAO data. This is difficult to do with the INCYTH data, multi temporal
satellite data are needed then.

6.2. The final result of the research

Figure 6.1 shows the classification of the satellite image of
Januari 1986. The classes in this image are defined with the SPSS
statistical package and the Ward method. These classes are given a
Kc-value based on crop, variety, groundcover, percentage dried plants
and undergrowth. The classification is done with the ERDAS image
processing system and the maximum likelihood decisionrule. The two
fallow classes shown in table 5.3 were merged.

In table 6.1 the division of the Kc-classes on the classified
image is noted.

FIGURE 6.1 Classified image of Viejo Retamo secondary unit showing areas with different crop classes (A, B, C, D and E) and the not cultivated area. (NI).

TABLE 6.1 Distribution of the Kc-classes in the Viejo Retamo

class number	Kc value	number of pixels	% area
1	1.)0	16875	16.11
2	0.90	27579	26.32
3	0.85	25380	24.22
4	0.80	15115	14.43
5	0.70	8178	7.81
6	Fallow	4328	4.31

7. RECOMMENDATIONS FOR FURTHER RESEARCH

- In further research, sufficient attention must be paid to the gathering of groundtruth (as in this study).

- In areas where crops are similar, the detailed groundtruth is essential.

- It is necessary to do further research on multi-temporal data of this area. According to the INCYTH data there should be a clear difference in Kc-values of fruittrees and grapes in September. A combination of a September image with the January image in a multi-temporal analysis, is expected to give good results.

- Other methods that were not used in this investigation should be tried out.

ANNEX

GROUNDTRUTH

The entire Viejo Retamo

The tertiary units with groundtruth

| vcd | : used groundtruth |
| vcd | : not used groundtruth |

cropcodes:

P	:	Parral	D	:	apricot
V	:	Vinedo	Da	:	peach
VcF	:	Vinedo with fruit	Pe	:	pear
VcPe	:	Vinedo with pear	M	:	Quinces
VcD	:	Vinedo with apricots	I	:	fallow
			Ab	:	abandoned

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SUMMARY

On behalf of a project on the use of irrigation water, a research is
done with the purpose to make a vegetation map using a TM- satellite
image. With this map the evapotranspiration in the different parts of
the study-area can be calculated.
Based on the availability of groundtruth and former cooperations, a
part of the Rio Tunuyan Irrigation Scheme in Mendoza, Argentina is
chosen as study-area. This is the area of influence of the Viejo
Retamo secondary canal.

Classes are defined and the image is classified with different methods
on the ERDAS image processing system. The formation of classes is also
done with the SPSS statistical package.

The class-formation methods are chequed on their capacity to
discriminate the crops, and on the reliability of the classification.

With the developed parameters is decided that the best classes were
made with the SPSS methods. The classification of the image is done
best with the ERDAS maximum likelihood decision rule.

Already in an early stage appeared that it is not possible to make
classes with just one crop in it, with the available groundtruth and
the TM-image of January 1986.
The most occuring crops in the area, vine and fruittrees, have much
similarity in spectral behaviour. This makes the discrimination of the
crops on the TM-image difficult. Another reason for this difficulty, is
the great difference between the fields with the same crop. This
difference is caused by p.a. the type of vineplants, the ground-cover
and the undergrowth.
Even with the best classification methods, the classes contained more
than one crop.