LUNDS UNIV. GEOGRAFISKA INST.

E83-10320
CR-170380

MONITORING LAND DEGRADATION IN SOUTHERN TUNISIA

A Test of Landsat Imagery and Digital Data

ULF HELLDEN and MIKAEL STERN

(E83-10320) MONITORING LAND DEGRADATION IN SOUTHERN TUNISIA: A TEST OF LANDSAT IMAGERY AND DIGITAL DATA (Lund Univ.) 43 p HC A03/MF A01 CSCL 08G
N83-27308
Unclas
G3/43 00320

Lunds Universitets Naturgeografiska Institution
Rapporter och Notiser 48

Lund 1980

MONITORING LAND DEGRADATION IN SOUTHERN TUNISIA.

A Test of Landsat Imagery and Digital Data

Ulf Helldén and Mikael Stern

Laboratory of Remote Sensing
Department of Physical Geography
University of Lund
Soelvegatan 13 Tel. no. 046/124600-1679
S-223 62 Lund
SWEDEN

Lund, September 1980 ISSN 0348-3339

CONTENTS

1. ABSTRACT

During 1979 a study on the possible use of Landsat imagery and digital data for monitoring desertification indicators in Tunisia was carried out. Field data were sampled in Tunisia for estimation of mapping accuracy in maps generated through interpretation of Landsat False Colour Composites (FCC) and processing of Landsat Computer Compatible Tapes (CCT) respectively. Temporal change studies were carried out through geometric registration of computer classified windows from 1972 to classified data from 1979. Indications on land degradation were noted in some areas. No important differences, concerning results, between the interpretation approach and the computer processing approach were found.

2. INTRODUCTION

During 1979 a study of southern Tunisia was carried out in order to test the reliability with which Landsat False Colour Composites (FCC) and digital data respectively, can be used as possible sources of information for environmental monitoring purposes. Environmental monitoring is necessary in order to aquire a better understanding of the causes and effects of the processes usually known as "desertification processes" or "land degradation processes" causing a decline in crop productivity and famines in many arid and semi-arid developing countries (Rapp and Helldén 1979). Environmental monitoring is also needed to obtain information for an ecologically sound land use planning and for a follow-up of the environmental impact of projects, implemented to counteract desertification, so that correction measures can be introduced when necessary. A large number of physical, biological/agricultural and social indicators of desertification were suggested at the Nairobi Seminar on Desertification in 1977 (Reining 1978). The indicators should be diagnostic and it was assumed that many of them could be surveyed and monitored using modern remote sensing techniques, including the use of satellite data.

The research was carried out in two steps. During the first step field data were sampled in Tunisia. The second stage included interpretation of Landsat FCC, computer classification of Landsat digital data, evaluation of mapping accuracy and temporal environmental change studies by means of geometrical registration of Landsat scenes from 1972 to 1979. Parts of the step were carried out using the Swedish Space Corporation computer based interactive Image Analysis System (IAS) for the processing of Landsat digital data. The remaining procedures were carried out at the Remote Sensing Laboratory, University of Lund.

The research was carried out within the the project "Regional Studies of Desertification and Its Control. - Approaches to Rehabilitation of Degraded Ecosystems in Africa" running at the Department of Physical Geography, University of Lund, in cooperation with research organisations in African countries. The project is based on ideas and recommendations presented in the report "Research on Environmental Monitoring Methods for Land Use Planning in African Drylands" (Rapp and Helldén 1979). and so far was financially supported by the Swedish Agency for Research Cooperation with Developing Countries (SAREC) and the Swedish Board for Space Activities (DFR).

During the field work in Tunisia, valuable support was offered by Dr. G. Novikoff. Valuable support was also offered by personnel at the Swedish Space Corporation during the processing of Landsat digital data. Financial support was recieved from SAREC, DFR and the Swedish Space Corporation. R. Laszlo helped with photographic work and C. Laszlo and E. Herbertsson assisted in map drawing at the Department of Physical Geography in Lund.

3. INTRODUCTION TO SOUTHERN TUNISIA

3.1. Climate

The Tunisian climate is of the Mediterranean type. Due to the subtropical high pressures, the summer is dry and warm. There are practically no effective rains from May to October.

The rest of the year is dominated by the westerlies and its cyclons, which causes a varying weather. Maximum precepitation generally occurs in autumn, but sometimes in winter or spring (Rapp et al. 1976). Rainfall increases with altitude along a gradient of 20-25 mm per 100 m, and rainfall variability increases with aridity (Le Houérou 1959). The distribution of mean annual precipitation is presented in Fig. 1., while the variability in annual rainfall of different bioclimatic zones is indicated in Table I.

3.2. Geology

Geological formations are all of a sedimentary nature, aged from Trias

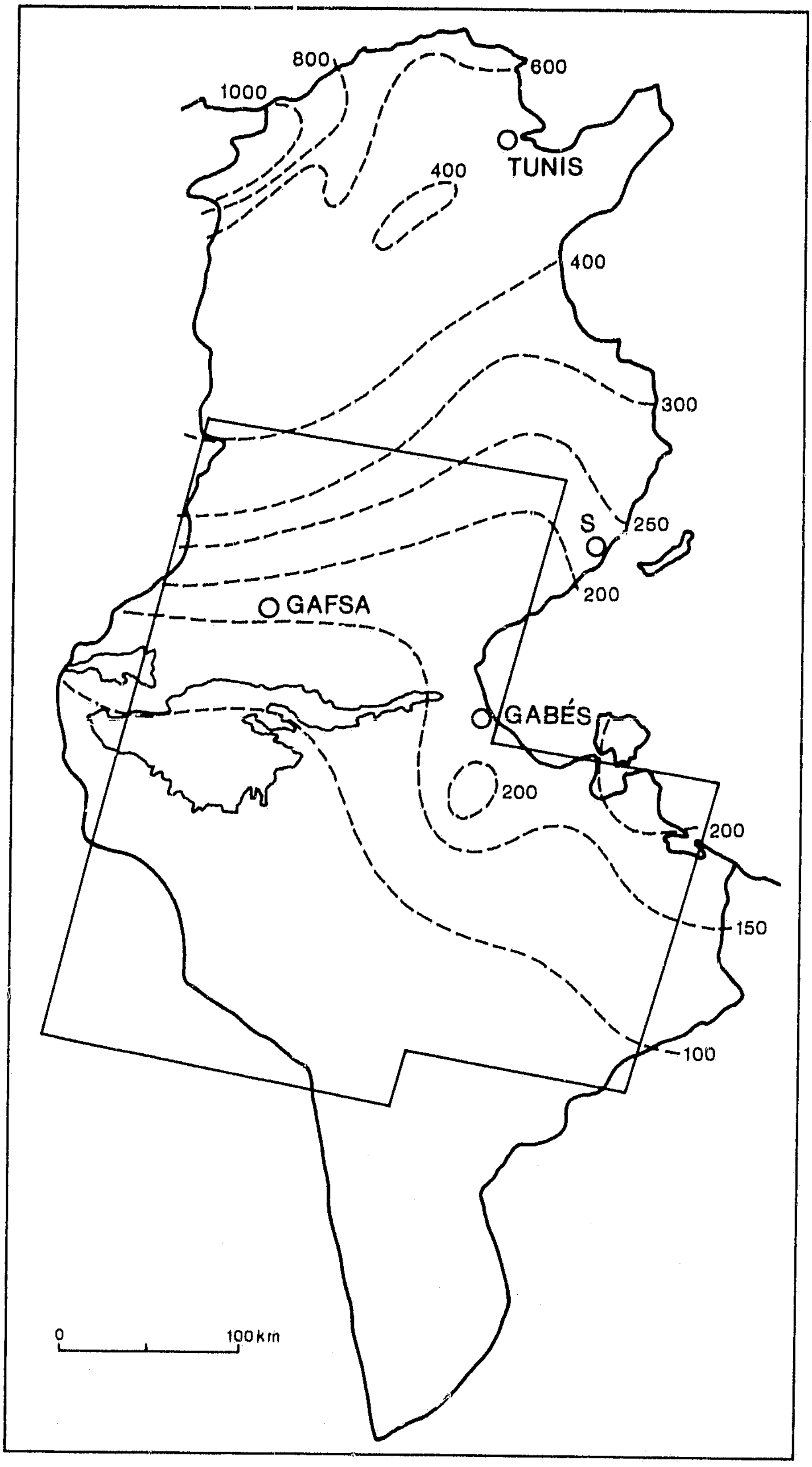


Fig. 1. Mean annual precipitation (mm) 1901-60. (Division de la Meteorologie Nationale 1971). The frame indicates the area covered by the thematic map presented in Fig. 9.

Table I. Variability in annual rainfall of different bioclimatic zones in Tunisia (from Rapp et al. 1976).

Rainfall variability	Bioclimate	Annual rainfall
30 - 40 %	upper arid	300 - 400 mm
40 - 50	middle arid	200 - 300
50 - 60	lower arid	100 - 200
60 - 80	Saharan	less than 100

to Quaternary with huge extension of Cretaceaous, Tertiary and Quaternary deposits. These sediments are alternatively of a neretic and continental origin. The lithological assemblage includes mainly limestones of different kinds alternating with marls and sandstones with gypseous and saline formations.

The sedimentary series were folded during the Atlasic orogenesis during Oligocene-Miocene time. There are three main chains:

-"Tunisian Backbone" (Dorsale Tunisienne), oriented SW-NE, stretching from Kasserine to Cap Bon and limiting the arid steppe zone towards the north.

-"Chott Range", oriented W-E, which lies immediately north of the large salt marshes of Chott-el Rharsa, Djerid and Fedjadj from Gafsa to Gabés and which roughly seperates the arid from the desert zone.

-"Matmata Chain", which is a tubular eastern end of the Sahara plateau and which seperates the Sahara from the Djeffara coastal plain (Rapp et al. 1976).

The El Hamma test area is dominated by Cretaceous and Quaternary deposits while the Medenine test area almost completely is of Quaternary age. The test areas mentioned are indicated in Fig. 2.

3.3. Soils

Except for the hydromorphic soils of the chotts and the regosols and lithosols of the mountainous areas, the El Hamma test area is dominated by saline soils and gypseous crusts.

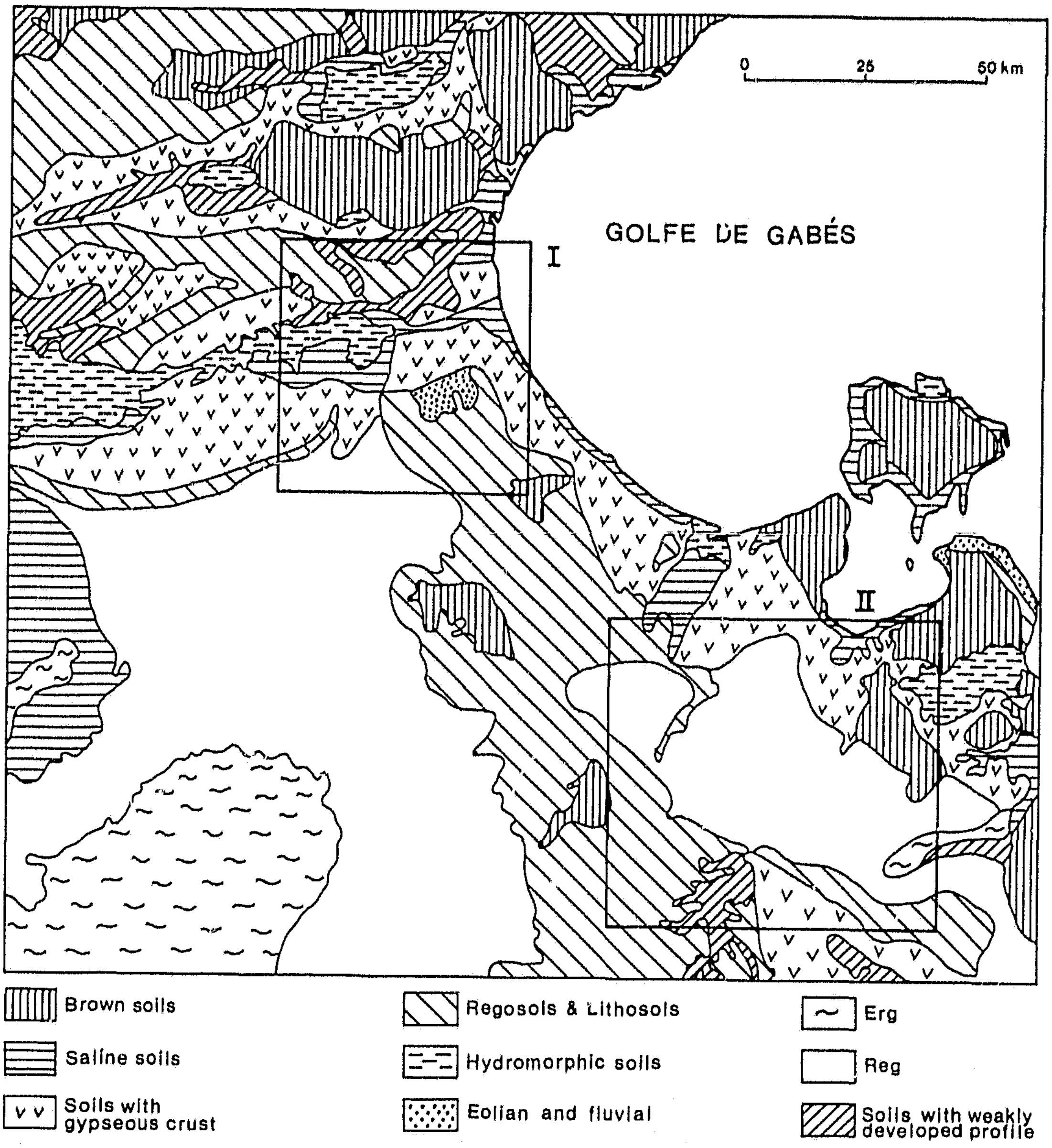


Fig. 2. Soils within the test areas (modified from Sols de Tunisie, 1971). I. El Hamma test area. II. Medenine test area.

The Medenine test area is dominated by reg and saline soils with gypseous crusts, but also brown soils are found here (Fig. 2)

3.4. Vegetation and land use

In southern Tunisia, between the 100 mm and 400 mm isohyet, several different types of steppe vegetation are represented. The desert zone extends south of the 100 mm isohyet and is characterized by vegetation distributed on a contracted pattern on the regs (Rapp et al. 1976).

The Djeffara (the name of the coastal plains west of the Matmata Mountains) includes most of the test areas. The vegetation is characterized by a steppic or shrub-desert type of vegetation cover with shrubs mostly less than 1 m in height, woody perennial forbs or half-shrubs, some perennial grasses and a diverse annual flora. A dominant species is the composite shrub Rhanterium suaveolens , especially on sandy soils. Part of the Djeffara are sometimes referred to as the "Rhanterium zone" (Novikoff et al. 1977).

Traditionally the Djeffara was mostly used for grazing (sheep and goats) by the nomads, and cultivation was rare. But just like in many other African countries, most of the nomads have settled during the last 20 years. This lead to incresing population and cultivation pressure. About 30% of the arid zone is cultivated nowadays (Hall et al. 1979). Landowners of this region prefers to grow olives and cereal grains (barley and wheat) as the major crops. The oasis are dominated by date cultivations.

3.5. Desertification

Central Tunisia southwards to the steppe areas of Gabés and Medenine is marked as a zone of very high risk of desertification on a detail of UNCOD world map of desertification simplified from FAO & UNESCO map 1977 (Rapp and Helldén 1979, p. 19). The area is characterized by high human and animal pressure and strong erosion by wind and water. Regarding the status of desertification, the Gafsa region in Tunisia was the only area in Africa classified as suffering from very severe desertification on a map presented by Dregne (1977).

Tens of thousands of hectares on the average are affected by desertification in southern Tunisia every year (Le Houérou 1976). Floret and Le Floch (1972) reported that firewood collection alone destroys 18,000 ha of steppe annually in the governorate of Gabés (Le Houérou 1976). Water erosion in the arid zone of Tunisia removes 0.5 - 1.5 mm of top soil per annum and the silt load of the wadis has been reported to be in the magnitude of 50 $kg \cdot m^{-3}$ according to the author mentioned. Wind erosion can remove several centimeters of topsoil per year after cereal cultivation or grazing on sandy soils creating a degraded steppe (Fig.14 a). It was illustrated by Rapp (1979, Fig. 11-12) how formerly intact steppe vegetation on sandy soil had been severely degraded by wind erosion after five years of grazing by goats, sheep and camels. In some places 15-20 cm of topsoil had been blown off during the five years. The importance of overcultivation, as one of the main causes of desertification in Tunisia, was stressed by Mensching and Ibrahim (1977) (Cf. Fig.14 b).

4. METHODS

4.1. General approach

The general approach used for generation of thematic maps based on remote sensing techniques was described by Helldén (1980). It includes the following steps in the order mentioned:

1. Unsupervised analysis and stratification of remotely sensed data for sampling of ground truth. (This step was not carried out beacuse of lacking Landsat data).
2. Sampling of ground truth data.
3. Generation of remotely sensed data in pictorial form for training procedure.
4. Training procedure.
5. Computer classification or manual interpretation.
6. Generation of thematic maps.
7. Estimation of indicators of mapping accuracy.
8. New choice of classes or new training procedure if the results of step 7 are not satisfactory.

4.2. Landsat data used

The following Landsat FCC and Computer Compatible Tapes (CCT) were purchased from EROS Data Center, U.S.A., and used in the study:

(Landsat-, Path/Row, Date, FCC and/or CCT),(Landsat-1, 206/36,09 Nov.-72, CCT,FCC), (Landsat-1, 205/37, 08 Nov.-72, FCC), (Landsat-1, 206/37, 09 Nov.-72, FCC), (Landsat-1, 206/36, 07 Feb.-73, FCC), (Landsat-1, 205/37, 08 Aug.-72, CCT). To obtain Landsat data recorded as close as possible to the ground truth sampling period, March 3 - March 13, 1979, the Fucino recieving station in Italy was asked in advance , through the Swedish Space Corporation, to recieve all Landsat MSS and RBV data covering central and southern Tunisia during the period December 1978-March 1979. Out of four ordered scenes the following two CCT:s were sufficiently cloud free to be used : (Landsat-3, 205/37. 19 March-79) and (Landsat-3, 206/36, 22 May-79).

4.3. Ground truth sampling

The sampling technique used in this study was described by Helldén and Olsson (1976) and Helldén (1978,1980). It is based on sampling from a car along almost all the available roads, tracks etc. within the areas concerned. A stop was made every kilometer when a square of 1 ha on both sides of the car was classified concerning land use, vegetation cover, soils and physical indicators of high pressure on land causing desertification (e.g. ripples, dunes, deflation patches, nebkas, gully and sheet erosion). The information was recorded and plotted on topographical maps to the scale of 1:200 000. During 11 days 4 052 points were sampled along more than 2 000 km of field traverses (Fig. 4.). Up to 2 843 of these points were used in the study.

4.4. Interpretation of Landsat FCC

Training, interpretation and mapping was carried out using a Stereo Facet Plotter (O.M.I.) and a Stereo Zoom Transfer Scope (Bausch & Lomb). The instruments are designed for the transmission of information from stereo models or single pictures to base maps of optional scales. The images can be optically adapted to the chosen base maps and differences in scale and distortion can be minimized. Topographical maps to the scale of 1:200 000 and in one case for a general survey in the scale of 1:1 million were used as base maps. Existing information regarding the base maps facilitated the interpretation. Less than 1% of the plotted field data were used during the training phase when the classes concerned were defined with regard to colour composition in the FCC:s.

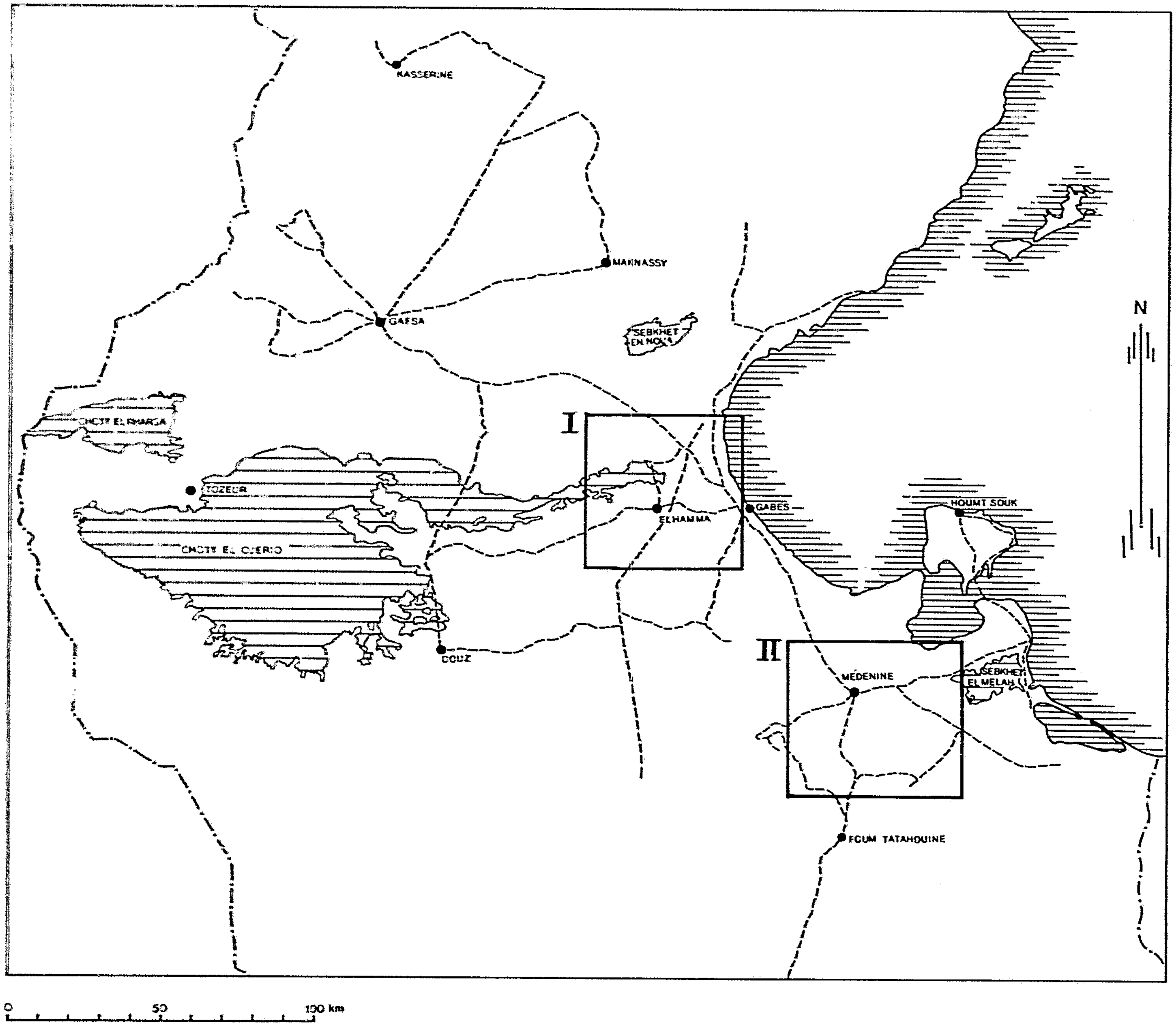


Fig. 4. Field traverses in central and southern Tunisia. Field data were sampled twice every kilometer.

I. El Hamma test area.
II. Medenine test area.

4.5. Processing and classification of Landsat digital data

The processing of Landsat CCT:s was carried out using the Swedish Space Corporation mini-computer based Image Analysis System (IAS) manufactured by MacDonald, Dettwiler & Associates Ltd (MDA) (Fig. 5). IAS is an interactive system for MSS geometric distortion calculations, geometric corrections, 512 x 512 image registration, image manipulation and combination (e.g. ratioing), image enhancement (e.g. destriping, edge and contrast enhancement), training and multispectral classification (Fig. 6).

The training procedure was carried out using less than 1% of existing field data for the Landsat window concerned (512 lines x 512 pixels). Appropriate training data, based on ground truth samples, were identified and delineated on a three band (MSS 4, MSS 5, MSS 7) false colour digital composite, displayed on the Comtal imaging CRT-system. A trackball system was used for the delimitation of training sets. A Maximum-Likelihood classifier was employed for all classifications. All four bands were included. In most cases three standard deviations were used as acceptance/rejection criteria during the classifications. Geometric registration of classified Landsat windows from 1972 to 1979 was performed using a nearest neighbour resampling procedure.

Classification results were displayed on the Comtal CRT and photographed, while statistics were generated on a printer. Colour hard copies of geometrically corrected classifications were also generated using an Applicon Ink Jet Plotter at the Stockholm University Computer Center (QZ). Before Ink Jet Colour plots were generated, a clean-up procedure was employed to get rid of odd pixels. Single pixels in a 3 x 3 scanning window were automatically changed to the class belonging of the majority of the neighbours within the window. Both the clean-up procedure and the generation of Ink Jet Colour plots could be carried our from the laboratory in Lund by using a terminal and printer connected to QZ in Stockholm . The terminal system was described by Helldén (1980). The procedure was carried out by using a software system for processing and classification of multispectral digital data, originally developed by the Swedish National Defence Research Institute (Åkersten and Gustafsson 1978) and since mid-1978 administrated and updated by the Swedish Space Corporation.

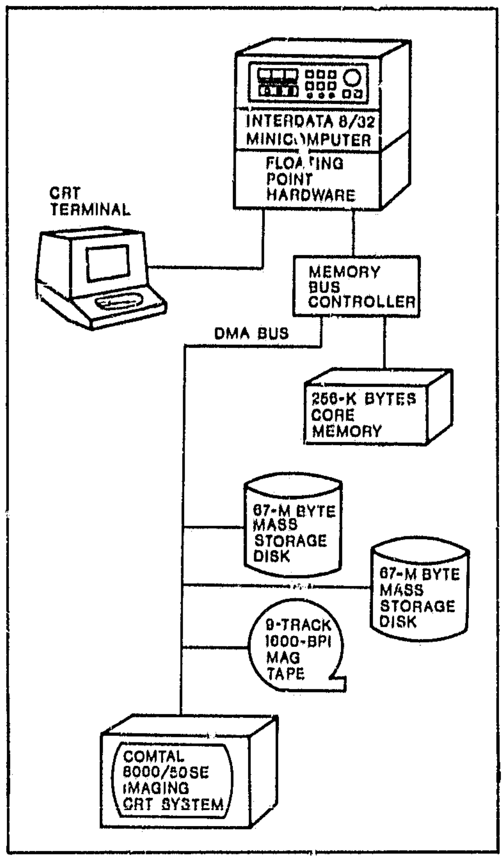
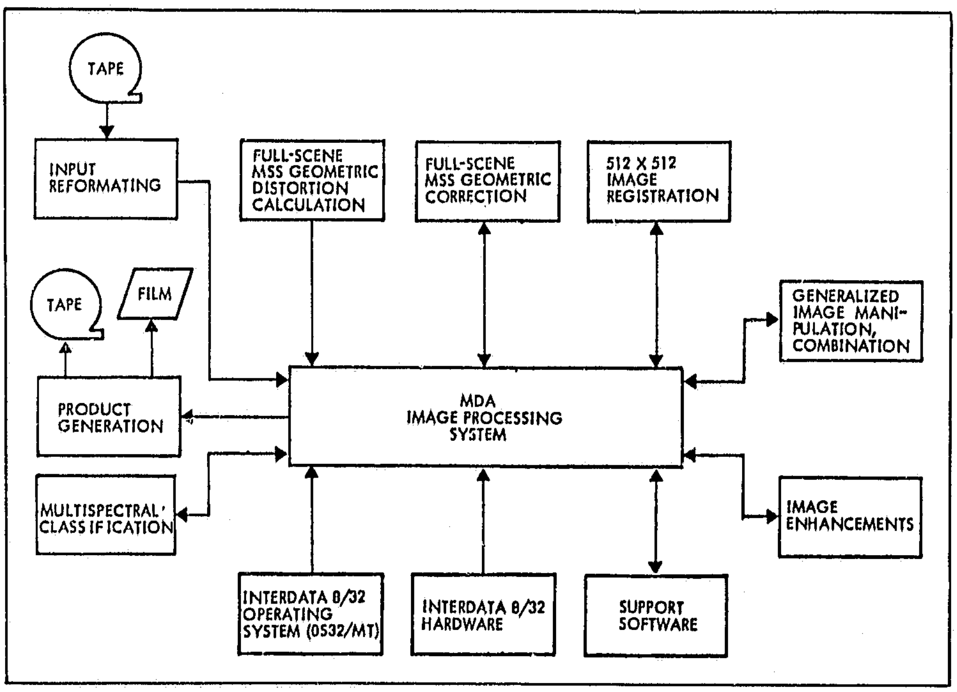


Fig.5. The Swedish Space Corporation Image Analysis System (IAS).

Fig. 6. IAS Top Level Image Processing System Functional Elements.



The program system is implemented on an IBM 370/165 at QZ. Included in the software is an interactive command procedure especially designed for terminal users (Wasteson and Åkersten 1978).

4.6. Methods for evaluation of indicators of mapping accuracy

The methods employed in this study for evaluation of mapping accuracy were presented by Helldén (1980). After a comparision of generated maps with ground truth (performed through co-projection of generated maps with the sampled ground truth data plotted on topographical maps) the indicators of mapping accuracy listed in Table II were estimated and tabulated using a computer program developed for the purpose. The concept of the indicators are illustrated in Fig. 7.

Stated confidence limits in the mapping accuracy tables were estimated at the 5%-level. i.e. the probability is 95% that presented means lie somewhere within the confidence limits and 5% that they lie outside these limits. The normal distribution function was used as an approximation of the binomial. A test is also included in the program to see whether stated areal differences are significant at the 5%-level. If not, the areal difference is printed as ZERO in the summary table. A **SMALL SAMPLE** warning is printed when the sample size is smaller than 30, indicating the lack of confidence in the presented results. A certain over representation of extensive classes and under representation of small classes or classes in which roads and tracks are not so frequent (e.g. playas) is a draw back in the sampling procedure used. It infers that presented figures for areal extension of individual classes, according to sampled field data and map data respectively, should not be interpreted as absolute measures of areas, but as relative units produced solely for the estimation of the reliability of generated thematic maps.

5. RESULTS

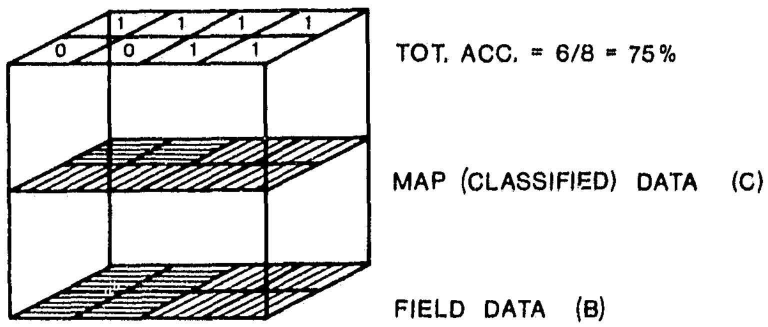
5.1. Generated maps

All generated maps originally included the following classes or variants of classes very similar to them:

Fig.7.The concept of the mapping accuracy indicators (from Helldén 1980).

1 = CORRECTLY MAPPED, 0 = WRONG

A = NUMBER OF CORRECTLY MAPPED DATA
FOR THE SPECIFIC CLASS



	OBJ.ACC.(A/C)	CLASSIFIC.ACC.(A/B)	MEAN ACC. (2*A/(B+C))	AREAL DIFF. ((C-B)/B)
	2/2 =100%	2/4 = 50%	4/6 =66,7%	-50%
	4/6 = 66,7%	4/4 = 100%	8/10 = 80%	+50%

Table II. Definition of the indicators of mapping accuracy (from Helldén 1980).

N=total number of control points
A=the number of correctly mapped data for a specific class
SUM A=the total number of correctly mapped data (all classes included)
B=the number of sampled field data for a specific class
C=the number of map data for a specific class.

Interpretation accuracy,classification accuracy: (A/B)*100 (%) denotes the probability that a randomly chosen point of a specific class in the field has a correspondence of the same class in the same position on the map.

Object accuracy: (A/C)*100 (%) denotes the probability that a randomly chosen point of a specific class on the map has a correspondence of the same class in the same position in the field (ground truth).

Areal difference: ((C-B)/B)*100 (%) denotes with how many per cent a specific class on the map has been overestimated (+) or underestimated (-) in relation to the sampled field data for that particular class.

Mean accuracy: (2*A/(B+C))*100 (%)denotes the probability that a randomly chosen point of a specific class on the map has a correspondence of the same class in the same position in the field and that a randomly chosen point in the field of the same class has a correspondence of the same class in the same position on the map.

Total accuracy: ((SUM A)/N)*100 (%) denotes the probability that a randomly chosen point on the map has a correspondence of the same class and in the same position in the field and that a randomly chosen point in the field has a correspondence of the same class and in the same position on the map.

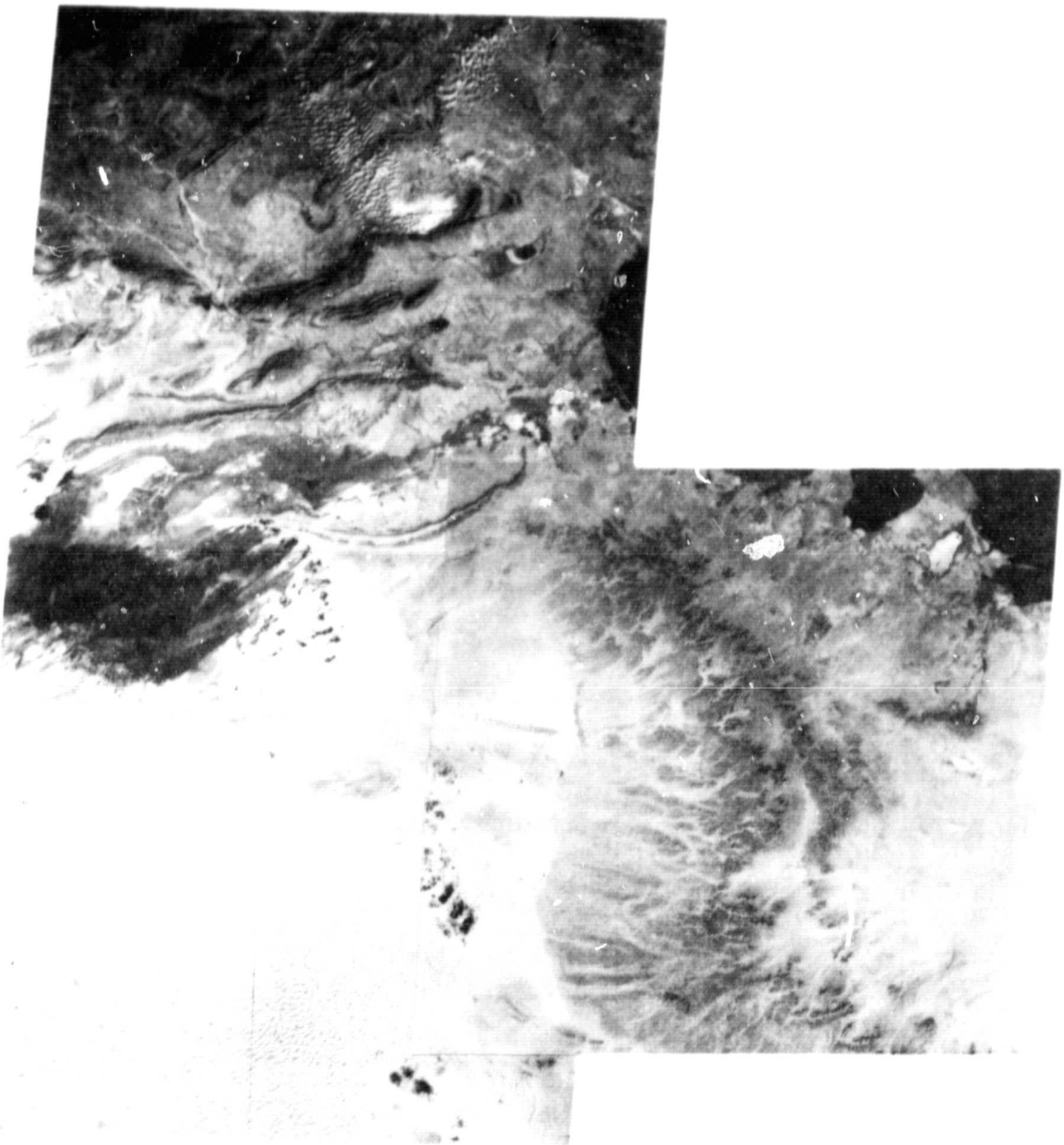


Fig. 8. Landsat-1 mosaic covering approx. 70 000 km^2 of central and southern Tunisia. Approx. scale 1:2 millions. Data recorded on Nov. 8-9, 1972. (Path and row, 205/37, 206/36, 206/37). MSS 5.

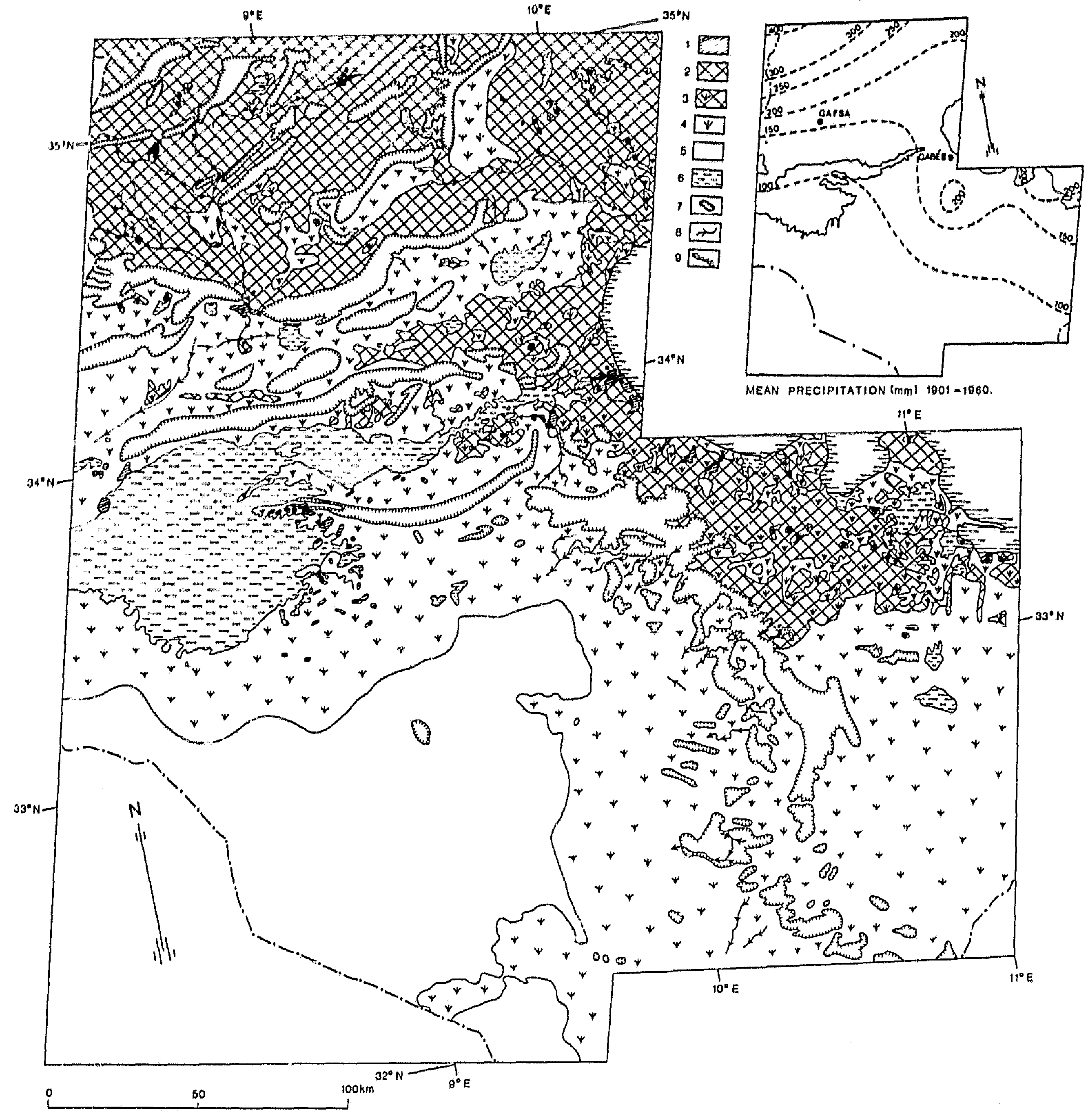


Fig. 9. Land use and vegetation map based on interpretation of Landsat-1 False Colour Composites (FCC) recorded November 1972. Classes: 1. Oasis and irregated land, 2. Cultivated land, 3. Cultivated and grazed land, 4. Grazed steppe, 5. Desert patch, 6. Chott (playa) with bordering chott vegetation, 7. Mountains, 8. Wadis, 9. Sea shore.

The framed map indicates the mean annual precipitation for the period 1901-1960 (after Division de la Meteorologie Nationale /1971/).

Fig. 10. Landsat-1 MSS 5 detail covering the El Hamma test area. Approx. scale 1:300 000. Data were recorded on Nov. 9,1972 (206/36). The frame indicates the area covered by the symbol coded printer plots in Fig. 12-13.

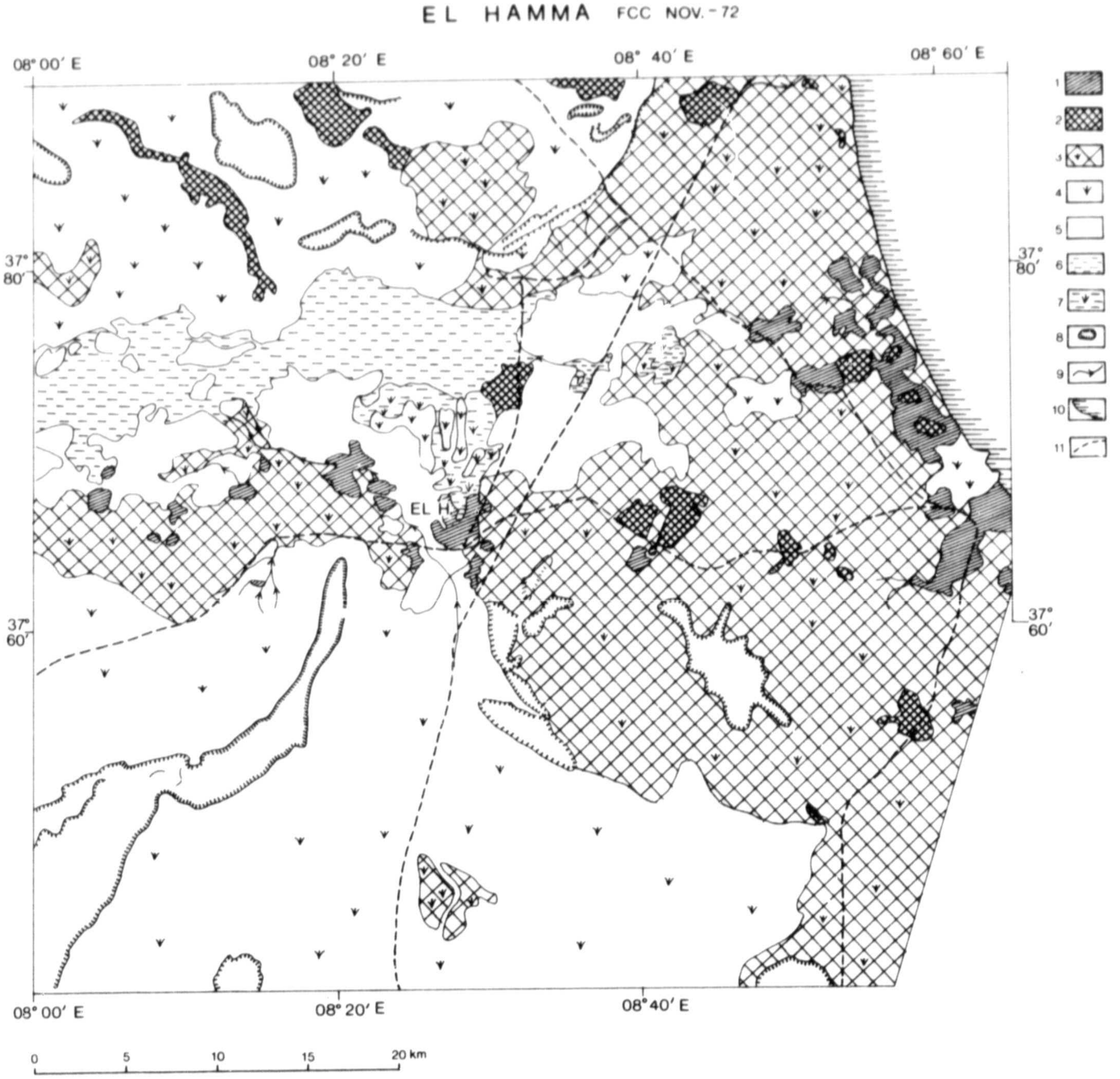


Fig. 11. Land use and vegetation map covering the El Hamma test area. The map is based on interpretation of a Landsat False Colour Composite (FCC). Data were recorded by Landsat-1 on November 9, 1972 (206/36). Classes:
1. Oasis and irrigated land, 2. Cultivated land, 3. Cultivated and grazed land, 4. Grazed steppe, 5. Desert patch, 6. Chott (playa), 7. Chott vegetation, 8. Mountains, 9. Wadis, 10. Sea shore, 11. Traverses for field data sampling.

Fig. 12. Example of a symbol coded printout covering the main part of the El Hamma test area. The El Hamma oasis is visible in the lower left corner. The printout is generated after a maximum-likelihood classification of Landsat-1 digital data recorded on Nov. 9, 1972. Each symbol represents one pixel. Aprox. scales: Horizontal 1:60 000 and Vertical 1:70 000. Classes: M=Oasis and irrigated land, -=Cultivated land, I=Grazed steppe, C=Chott, Blank=Overgrazed steppe and desert patch. (Scene 206/36).

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Fig. 13. Illustration of the effects of the clean-up procedure used. Input data are those presented in Fig. 12. All pixels and lines are included in both figures causing the geometrical distortion. Approx. scale: Horisontal 1:60 000 and Vertical 1:70 000. A indicates the area of alfalfa illustrated in Fig. 14 b.(For location cf. Fig.1

Fig. 14a. Detail of overgrazed and wind eroded Rhanterium steppe close to El Hamma.(Photo U. Helldén,March 1979.)

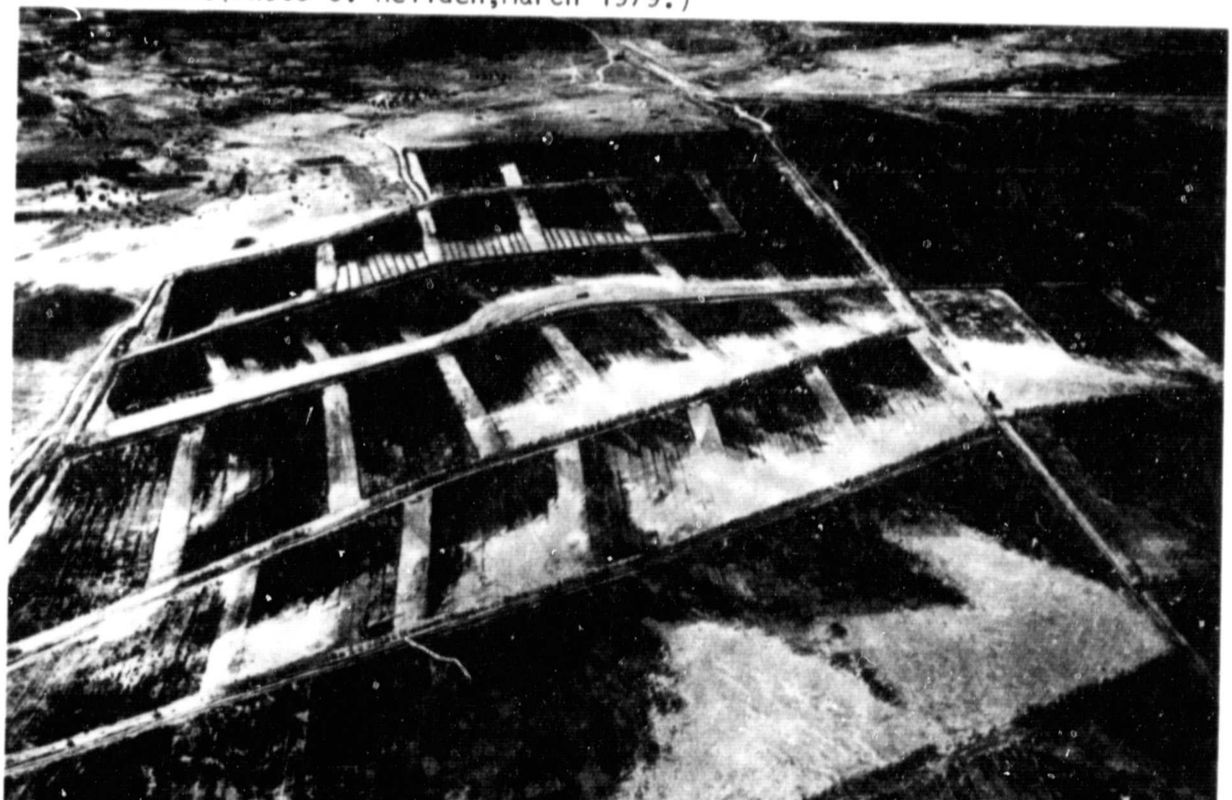

Fig. 14b.Aerial photo of damage to irrigated alfalfa cultivation.Floods of December 1973 deposited water transported sand along irrigation canals.Wind transport later increased the damage by drifting sand over crops.No signs of drifting sand within these cultivations were detected on the Landsat 1979 data. Position of the area is indicated in Fig.13. (Photo A.Rapp, 1974-03-15)(From Rapp/1978/).

* Oasis and irrigated land: (Cf. Fig. 14 b).

  Irrigated and intensively cultivated areas. The oasis mainly consist of palm trees (date palms).

* Cultivated land:

  Land dominated by dryland cultivation , mainly wheat and barley but also including non-irrigated olive cultivations.

* Grazed steppe:

  Mainly Rhanterium steppe.

* Overgrazed steppe:

  Sparse vegetation cover with sand elements such as small and scattered ripple fields, dunes, deflation patches and nebkas generated mainly through overgrazing and over-cultivation.

* Desert Patch:

  Barren land generated through overexploitation.

* Chott:

  Salt marshes, playas.

* Chott vegetation:

  Bush vegetation bordering the chotts.

To obtain a general overview of southern Tunisia a map to the scale of 1:1 million was generated through interpretation of three Landsat FCC:s recorded in November 1972 (Fig. 8-9). The map covers an area of approx. 70 500 km^2.

The detailed studies covered the two test areas El Hamma and Medenine approx. 50 x 50 km and 60 x 60 km respectively (Fig. 10-16). Two sets of maps were generated for each area. One set based on Landsat CCT and FCC, respectively, was recorded in mid autumn 1972 (at the end of the dry season long after crop harvest) and one set was recorded in spring 1979 (in May for El Hamma and March for Medenine) at the end of the winter rains and close to crop harvest. This choise was made to ensure that possible increases in the size and presence of desert patches, indicated in the Landsat data, should reflect true conditions (minimal change) instead of differences in e.g. soil water budget and vegetation stage caused by differences in local climate conditions.

5.2. Mapping accuracy

An output of the estimation of mapping accuracy indicators for the 1:1

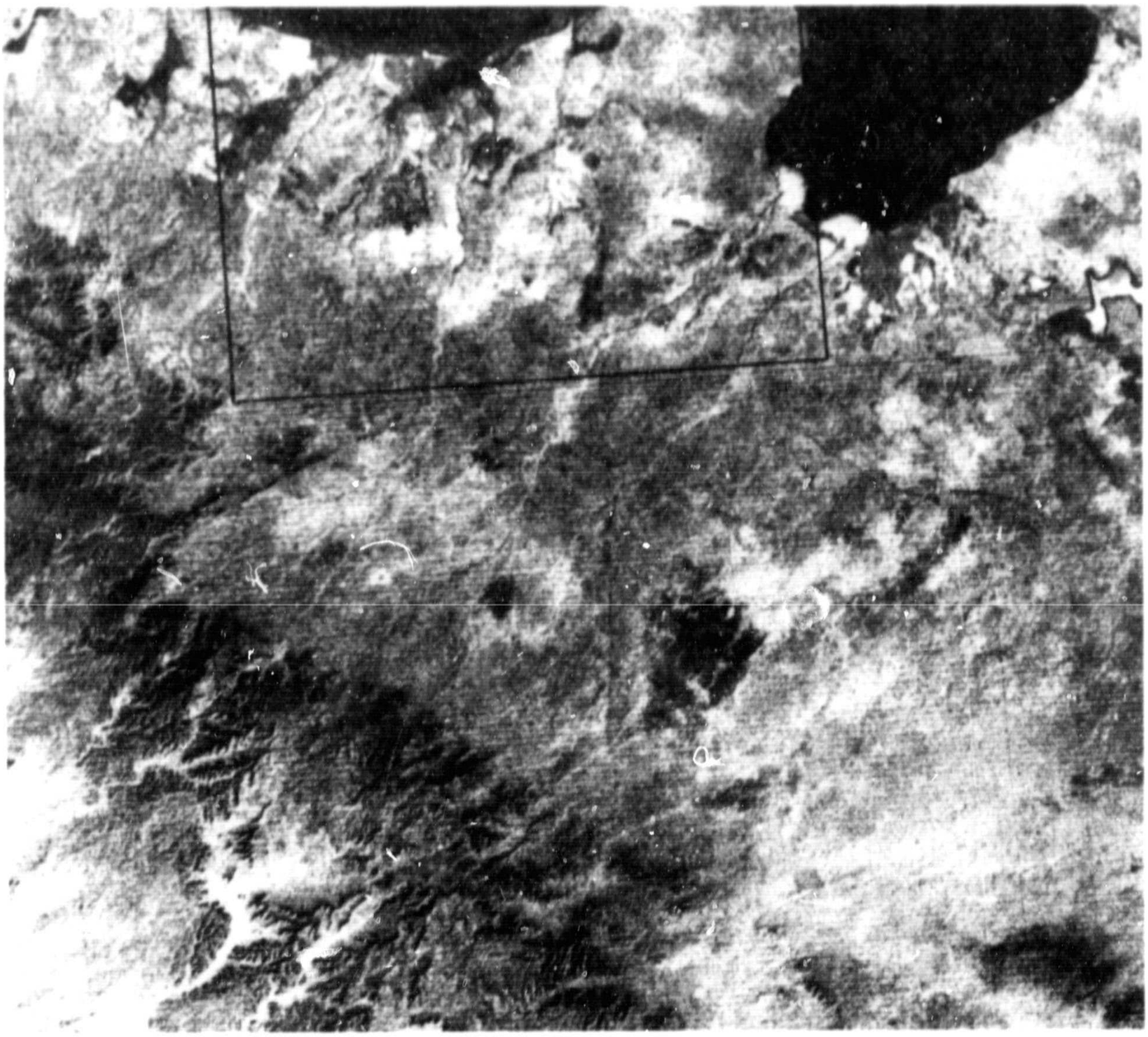

Fig. 15. Landsat-1 MSS 5 detail covering the Medenine test area. Data were recorded on Nov. 8,1972 (205/37). Approx. scale 1:480 000. The frame indicates the area covered by the Ink Jet Colour Plot presented in Fig. 20.

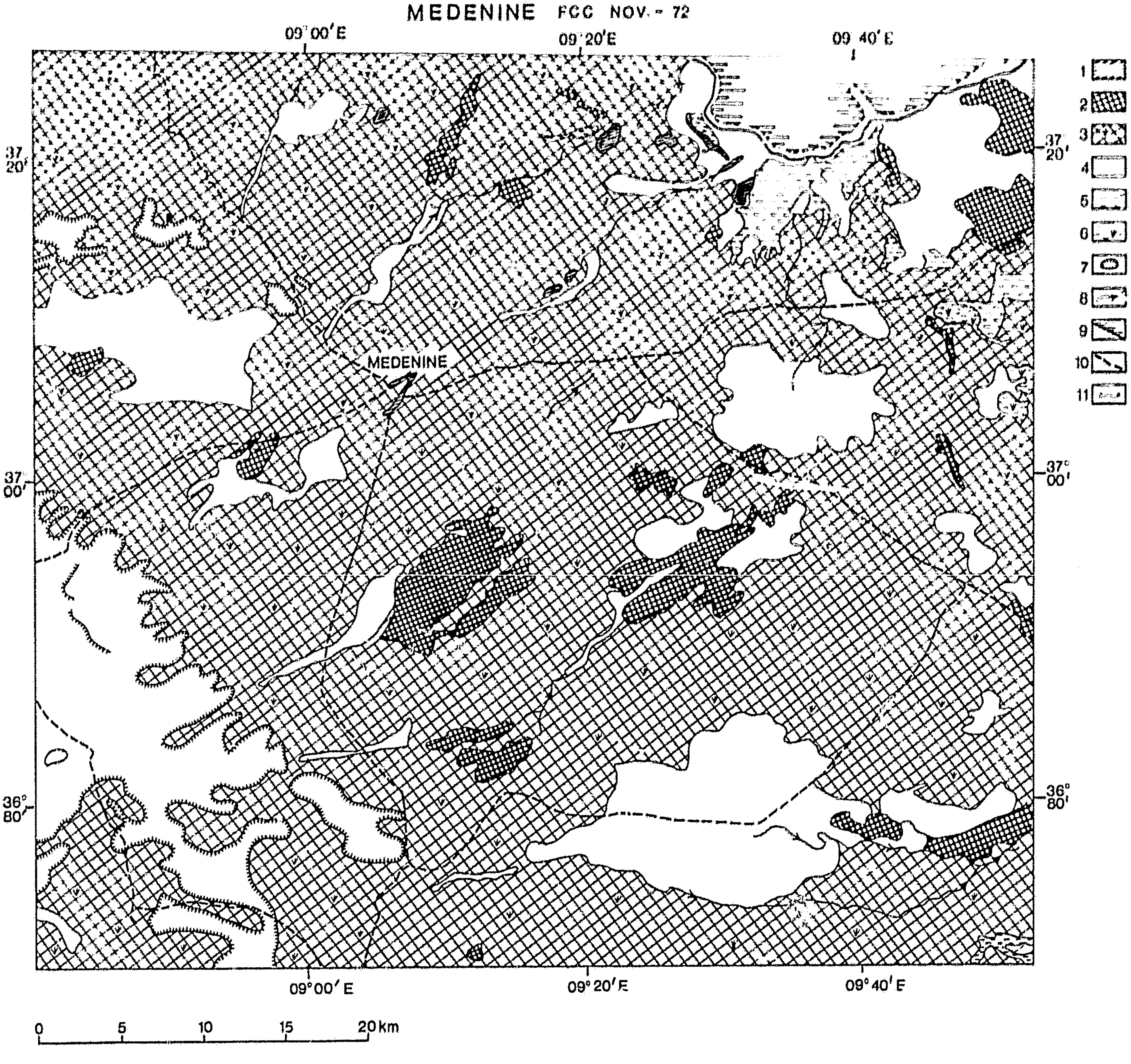

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Fig. 16. Land use and vegetation map covering the Medenine test area. The map is based on a Landsat-1 False Colour Composite (FCC). Landsat data were recorded on November 8, 1972 (205/37). Classes:
1. Oasis and irrigated land, 2. Cultivated land, 3. Cultivated and grazed land, 4. Desert patch, 5. Chott (playa), 6. Chott vegetation, 7. Mountain, 8. Wadis, 9. Sea shore, 10. Field traverse for ground truth data sampling, 11. Shallow coast water.

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Table III. Estimation of the mapping accuracy indicators for the 1:1 million scale map presented in Fig. 9.

FCC TUNISIA NOV-72 (LANDSAT-1)

OBJECT ACCURACY IN PERCENTAGE OF THE NUMBER OF CONTROL POINTS (N)

CL.	N	1	2	3	4	5	6	ERROR (%)	
1 .	67	81	18	0	1	0	0	19	OASIS/IRRIGATED LAND
2 .	922	0	73	2	25	0	0	27	CULTIVATED LAND
3 .	498	0	1	88	11	0	0	12	CULTIVATED/GRAZED
4 .	1262	1	9	2	88	1	0	12	GRAZED LAND
5 .	48	0	0	0	31	65	4	35	DESERT PATCH
6 .	46	0	9	0	0	0	91	9	CHOTT/CHOTT VEG
TOTAL	2843								

AREAL DIFF. (F), DISTR. OF FIELD AND MAP DATA. (CONF. LIMITS AT THE 5 %-LEVEL)

FIELD	DATA	REMOTE	SENSING	DATA (MAP DATA)	
CL. N1	AREA (%)	N2	AREA (%)	F (%)	SIGNIFICANT DIFF.
1 . 64	2 +- 1	67	2 +- 1	5	NO
2 . 803	28 +- 2	922	32 +- 2	15	YES
3 . 474	17 +- 1	498	18 +- 1	5	NO
4 . 1414	50 +- 2	1262	44 +- 2	-11	YES
5 . 44	2 +- 0	48	2 +- 0	9	NO
6 . 44	2 +- 0	46	2 +- 0	5	NO
TOT. : 2843		2843			

F=((N2-N1)/N1)*100 (%)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC. >= 70 (%), AREAL DIFF., (F), <=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC.	(%)
1 .	OASIS/IRRIGATED LAND	ZERO	82 +- 7	ACCEPTABLE
2 .	CULTIVATED LAND	15	78 +- 2	ACCEPTABLE
3 .	CULTIVATED/GRAZED	ZERO	90 +- 2	ACCEPTABLE
4 .	GRAZED LAND	-11	83 +- 1	ACCEPTABLE
5 .	DESERT PATCH	ZERO	67 +- 10	
6 .	CHOTT/CHOTT VEG	ZERO	93 +- 5	ACCEPTABLE
ALL CLASSES.	TOTAL ACCURACY:		83 +- 1	(%).

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ. ACCURACY=(A/C)*100(%), AREAL DIFFERENCE, (F)=((C-B)/B)*100 (%)
MEAN ACC. =(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%), TOTAL ACC. =((SUM A)/N)*100

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million scale map is illustrated in Table III. The summary of the table indicates that all classes, except for nr. 5, desert patch, were mapped with acceptable accuracy. The acceptance criteria in this study is that the mean accuracy should be at least 70% and that the areal difference must be less than /30/%.

It can be noted from the object accuracy table that 81% of the 67 control points on the map were correctly mapped for class 1., oasis/irrigated land. 18% of that which was mapped as oasis/irrigated land proved to belong to class 2.,cultivated land, according to field data. 1% of the control points on the map showed up as belonging to class 4., grazed steppe, according to field data resulting in a total error of 19%. The figures were mentioned in order to help the reader to interprete the table.

After the evaluation of mapping accuracy of the "detailed" maps, covering the El Hamma and Medenine areas, it was found that all classes tested could not be mapped with an acceptable degree of accuracy. Only the summaries of the evaluation results are presented (Tables IV-V).

The results were not surprising. This is indicated in the spectral diagram illustrated in Fig. 17. The reflectance means (from MSS 4,5,6,7) including one standard deviation are plotted for three classes in the diagram. The difficulties to separate the classes are indicated by the overlap pattern of digital greytone levels (DGL) in the four MSS-bands. It should be noted that three standard deviations were used in most of the classifications.

Based on the evaluation of mapping accuracy new classes were formed through compilation of some of the original classes thus giving:

* Oasisis and irrigated land
* Cultivated and grazed land
* Desert and overgrazed land
* Chott and chott vegetation

In most cases these new classes could be mapped with a mean accuracy close to,or exceeding,80% regardless whether the generated maps were based on interpretation of FCC or classification of digital data (Table VI - VII).

After having compared maps based on 1972 data with maps based on 1979 data no general trend could be found indicating that the individual

Table IV. Estimation of the mapping accuracy indicators for the El Hamma and Medenine test areas. Summaries only.

FCC. EL Hamma May-79 (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 .	OASIS/IRR	ZERO	94 +- 8	ACCEPTABLE **SMALL SAMPLE**
2 .	CULTIVATED LAND	-33	76 +- 8	
3 .	GRAZED LAND	122	61 +- 7	
4 .	OVERGRAZED	-58	55 +- 8	
5 .	DESERT PATCH	ZERO	93 +- 13	ACCEPTABLE **SMALL SAMPLE**
6 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		67 +- 6 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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FCC. El Hamma Nov.-72 (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 .	OASIS/IRR	ZERO	96 +- 6	ACCEPTABLE **SMALL SAMPLE**
2 .	CULTIVATED LAND	ZERO	56 +- 14	**SMALL SAMPLE**
3 .	CULT/GRAZED	39	78 +- 5	
4 .	GRAZED LAND	-31	69 +- 6	
5 .	DESERT PATCH	ZERO	91 +- 6	ACCEPTABLE
6 .	CHOTT	1100	15 +- 20	**SMALL SAMPLE**
7 .	CHOTT VEGETATION	-92	15 +- 20	**SMALL SAMPLE**
8 .	RIPARIAN VEG	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		74 +- 4 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. El Hamma Nov.-72 (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 .	OASIS/IRR	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
2 .	CULTIVATED LAND	-33	73 +- 8	
3 .	GRAZED LAND	80	62 +- 8	
4 .	OVERGRAZED LAND	-93	13 +- 9	**SMALL SAMPLE**
5 .	DESERT PATCH	67	73 +- 8	
6 .	CHOTT/CHOTT VEG	ZERO	89 +- 15	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		66 +- 6 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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Table V. Estimation of the mapping accuracy indicators for the El Hamma and Medenine test areas. Summaries only.

CCT. Medenine March-79 (Landsat-3)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)		
1 .	OASIS/IRR	ZERO	74 +- 20		**SMALL SAMPLE**
2 .	CULTIVATED LAND	ZERO	77 +- 5	ACCEPTABLE	
3 .	GRAZED LAND	ZERO	33 +- 12		**SMALL SAMPLE**
4 .	OVERGRAZED LAND	ZERO	72 +- 6		
5 .	DESERT PATCH	ZERO	100 +- 0	ACCEPTABLE	**SMALL SAMPLE**
6 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE	**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		71 +- 5 (%).		

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ. ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. El Hamma May-79 (Landsat-3)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)		
1 .	OASIS/IRR	ZERO	100 +- 0	ACCEPTABLE	**SMALL SAMPLE**
2 .	CULTIVATED LAND	ZERO	79 +- 8	ACCEPTABLE	
3 .	GRAZED LAND	320	36 +- 11		
4 .	OVERGRAZED LAND	-36	70 +- 7		
5 .	DESERT PATCH	ZERO	81 +- 13		**SMALL SAMPLE**
6 .	CHOTT/CHOTT VEG	ZERO	88 +- 13	ACCEPTABLE	**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		72 +- 6 (%).		

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ. ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. Medenine Aug.-72 (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)		
1 .	OASIS/IRR	ZERO	91 +- 12	ACCEPTABLE	**SMALL SAMPLE**
2 .	CULTIVATED LAND	-21	71 +- 6		
3 .	GRAZED LAND	-53	16 +- 10		**SMALL SAMPLE**
4 .	OVERGRAZED LAND	44	69 +- 5		
5 .	DESERT PATCH	ZERO	78 +- 11		**SMALL SAMPLE**
6 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE	**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		67 +- 5 (%).		

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ. ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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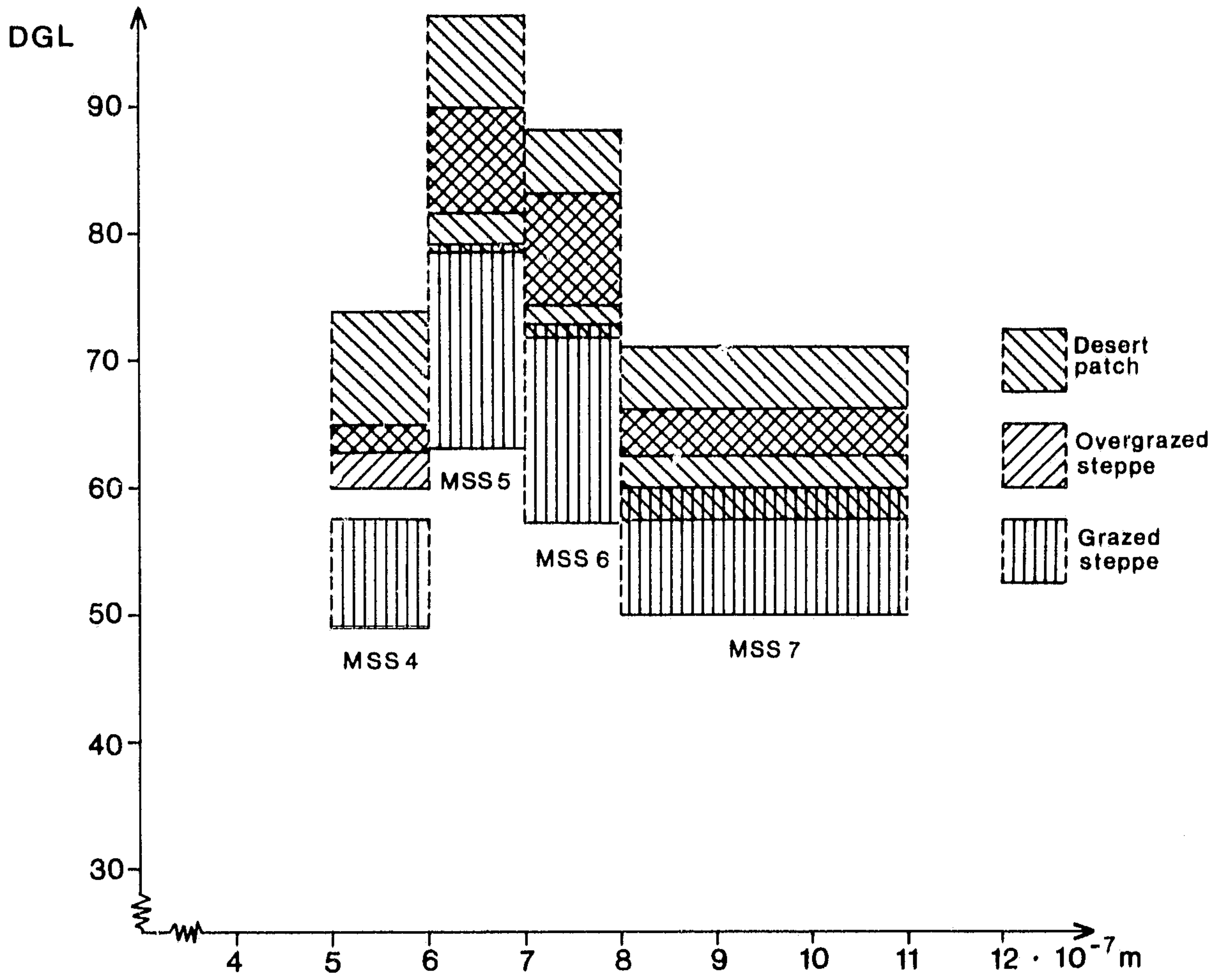

Fig. 17. Spectral diagram for the classes desert patch, overgrazed steppe and grazed steppe based on the digital greytone level (DGL) of approx. 3 000 training pixels in the El Hamma test area. One standard deviation is plotted around each reflectance mean.

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Table VI. Estimation of mapping accuracy indicators for the El Hamma and Medenine test areas. Classification with 4 classes only. Summaries.

FCC. El Hamma Nov.-72. Compiled classes (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC.	%)	
1 .	OASIS/IRR/RIP	ZERO	96 +- 5	ACCEPTABLE	**SMALL SAMPLE**
2 .	CULTIVATED/GRAZED	27	79 +- 4	ACCEPTABLE	
3 .	DESERT/OVERGRAZED	-24	78 +- 4	ACCEPTABLE	
4 .	CHOTT/CHOTT VEG	ZERO	69 +- 18		**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		79 +- 4	(%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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FCC. El Hamma May-79. Compiled classes (Landsat-3)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC.	(%)	
1 .	OASIS/IRR	ZERO	94 +- 8	ACCEPTABLE	**SMALL SAMPLE**
2 .	CULIVATED/GRAZED	46	79 +- 5		
3 .	DESERT/OVERGRAZED	-55	59 +- 8		
4 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE	**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		74 +- 5	(%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. El Hamma Nov.-72. Compiled classes (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC.	(%)	
1 .	OASIS/IRR	ZERO	97 +- 6	ACCEPTABLE	**SMALL SAMPLE**
2 .	CULTIVATED/GRAZED	ZERO	91 +- 4	ACCEPTABLE	
3 .	DESERT/OVERGRAZED	ZERO	88 +- 5	ACCEPTABLE	
4 .	CHOTT/CHOTT VEG	ZERO	89 +- 15	ACCEPTABLE	**SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		90 +- 4	(%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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Table VII. Estimation of the mapping accuracy indicators for the El Hamma and Medenine test areas respectively. Classification with four classes only. Summaries.

CCT. El Hamma May-79. Compiled classes (Landsat-3)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 .	OASIS/IRR	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
2 .	CULTIVATED/GRAZED	44	80 +- 6	
3 .	DESERT/OVERGRAZED	-32	79 +- 6	
4 .	CHOTT/CHOTT VEG	ZERO	88 +- 13	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		82 +- 5 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. Medenine Aug.-72. Compiled classes (Landsat-1)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70 (%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 ,	OASIS/IRR	ZERO	91 +- 12	ACCEPTABLE **SMALL SAMPLE**
2 ,	CULTIVATED/GRAZED	-28	68 +- 6	
3 ,	DESERT/OVERGRAZED	27	77 +- 5	ACCEPTABLE
4 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		74 +- 5 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA,, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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CCT. Medenine March-79. Compiled classes (Landsat-3)

SUMMARY
******* (CONFIDENCE LIMITS AT THE 5 %-LEVEL)
ACCEPTANCE CRITERIA: MEAN ACC.>= 70.(%), AREAL DIFF.,(F),<=/ 30 /(%).

CL.	CLASSES	F (%)	MEAN ACC. (%)	
1 .	OASIS/IRRIGATED LAND	ZERO	74 +- 20	**SMALL SAMPLE**
2 .	CULTIVATED/GRAZED	ZERO	79 +- 4	ACCEPTABLE
3 .	DESERT/OVERGRAZED	ZERO	73 +- 6	
4 .	CHOTT/CHOTT VEG	ZERO	100 +- 0	ACCEPTABLE **SMALL SAMPLE**
ALL CLASSES.	TOTAL ACCURACY:		76 +- 5 (%).	

A=NUMBER OF CORRECTLY MAPPED DATA, B=FIELD DATA, C=MAP DATA FOR EACH CLASS.
OBJ.ACCURACY=(A/C)*100(%), AREAL DIFFERENCE,(F)=((C-B)/B)*100 (%)
MEAN ACC.=(2*A/(B+C))*100 (%), 0<=MEAN ACC.<=100 (%),TOTAL ACC.=((SUM A)/N)*100

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classes were mapped with a higher mapping accuracy on the 1979 maps than the 1972 maps. The result is somewhat surprising as field data for both training and estimation of mapping accuracy were sampled in March 1979 (Fig. 18).

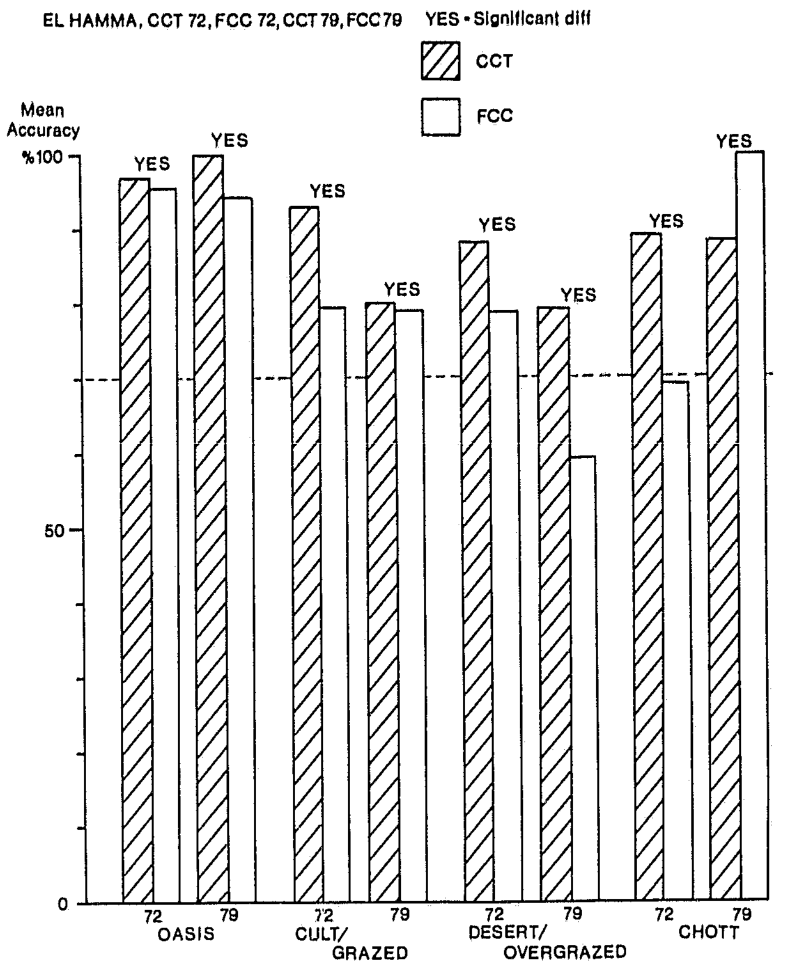

Fig. 18. Mean accuracy,based on approx. 1 000 control points, for the El Hamma area mapped through interpretation of Landsat FCC and processing of Landsat digital data respectively. Significant differences in mean accuracy between CCT and FCC based maps were tested at the 5%-level. The acceptance level is indicated at the 70% mean accuracy level.

A comparison of mean accuracy in all "detailed" maps generated from CCT (El Hamma 1972,1979 and Medenine 1972,1979) with all detailed maps generated through interpretation of FCC (El Hamma 1972, 1979 and Medenine 1972) included more than 2 000 control points. The comparison indicated that no general difference in mapping accuracy exists between the two methods (Fig. 19). A similar comparison of El Hamma data only (1972 and 1979), including more than 1 000 control points, did however suggest that maps based on computer classifications were somewhat better than those based on interpretation of FCC:s (Fig. 18)

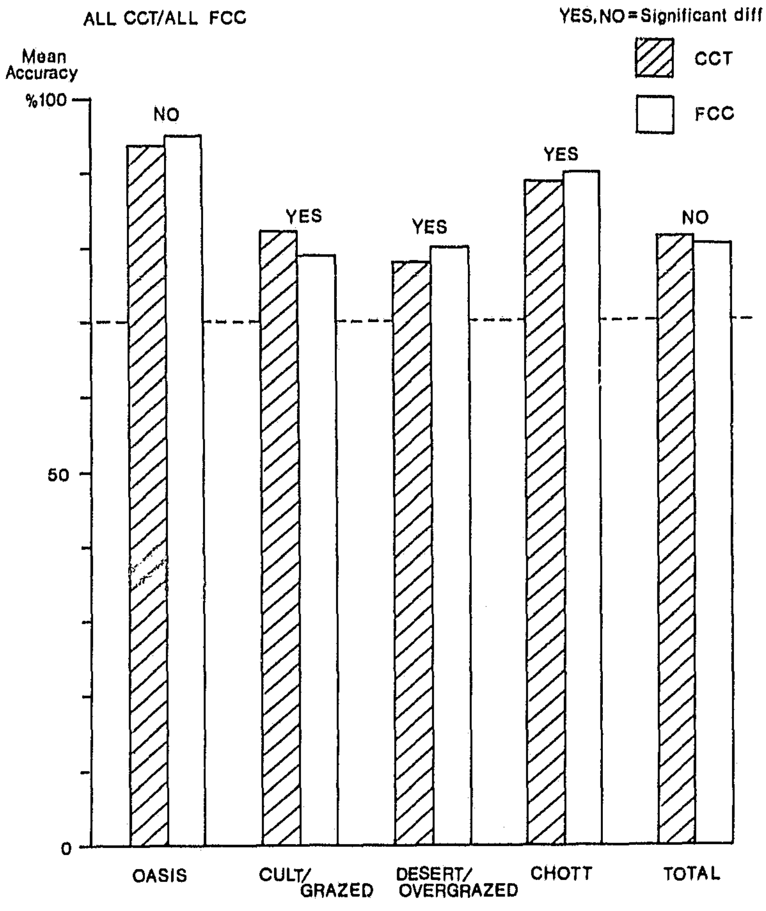

Fig. 19. Mean accuracy, based on more than 2 000 control points, for all "detailed" maps generated from CCT (El Hamma 1972,1979 and Medenine 1972,1979) and interpretation of FCC (El Hamma 1972,1979 and Medenine 1972) including the four compiled classes. The acceptance level is indicated on the 70% mean accuracy level. Significant differences were tested on the 5%-level.

It should be pointed out that all thematic maps based on interpretation of Landsat FCC were generated before the computer classification started. The interpretations were carried out by two different operators, one experienced and one less experienced, which may have affected the results to some extent.

5.3. Studies of environmental transformation

By geometric registration of desert patches from the 1972 digital classification to the 1979 digital classification it was possible to automatically monitor new desert patches. The results suggest that some of the desert patches in the Medenine area had increased in size during the period 1972-1979 and that a few new desert patches had been formed (Fig. 20).

The results also suggest that several of the desert patches in the El Hamma area had decreased during the same period. According to the analysis, the respective event occured rather close to the transition zone between dryland dominated by cultivation and steppe dominated by grazing. It has not been possible to confirm if the suggested changes are true or not. The mapping accuracy results imply, however, that suggested changes might be due to errors in the classification procedures and that no detectable environmental transformations actually took place during the period. The impact of differences in soil water budget and other physical factors affecting the spectral respons at the two different occasions (1972 and 1979) are unknown. It was reported by Helldén and Mattsson (1979) how the tracks of two weeks old rain showers showed up as distinct bands on Landsat imagery covering southern Tunisia. The dark bands were supposed to indicate higher soil water content in contrast to the dryer surroundings. These rains might very well have affected the results of the environmental change studies suppressing information about desert patches increasing in size and number.

6. DISCUSSION AND CONCLUSIONS

Achieved results imply that 4 to 6 land use and vegetation classes, with relevance to desertification studies and land use planning, could be surveyed through interpretation or computer classification of Landsat data for the given physical environment. This can be carried out within

Desert encroachment 1972-1979 according to analysis and classification of Landsat data.

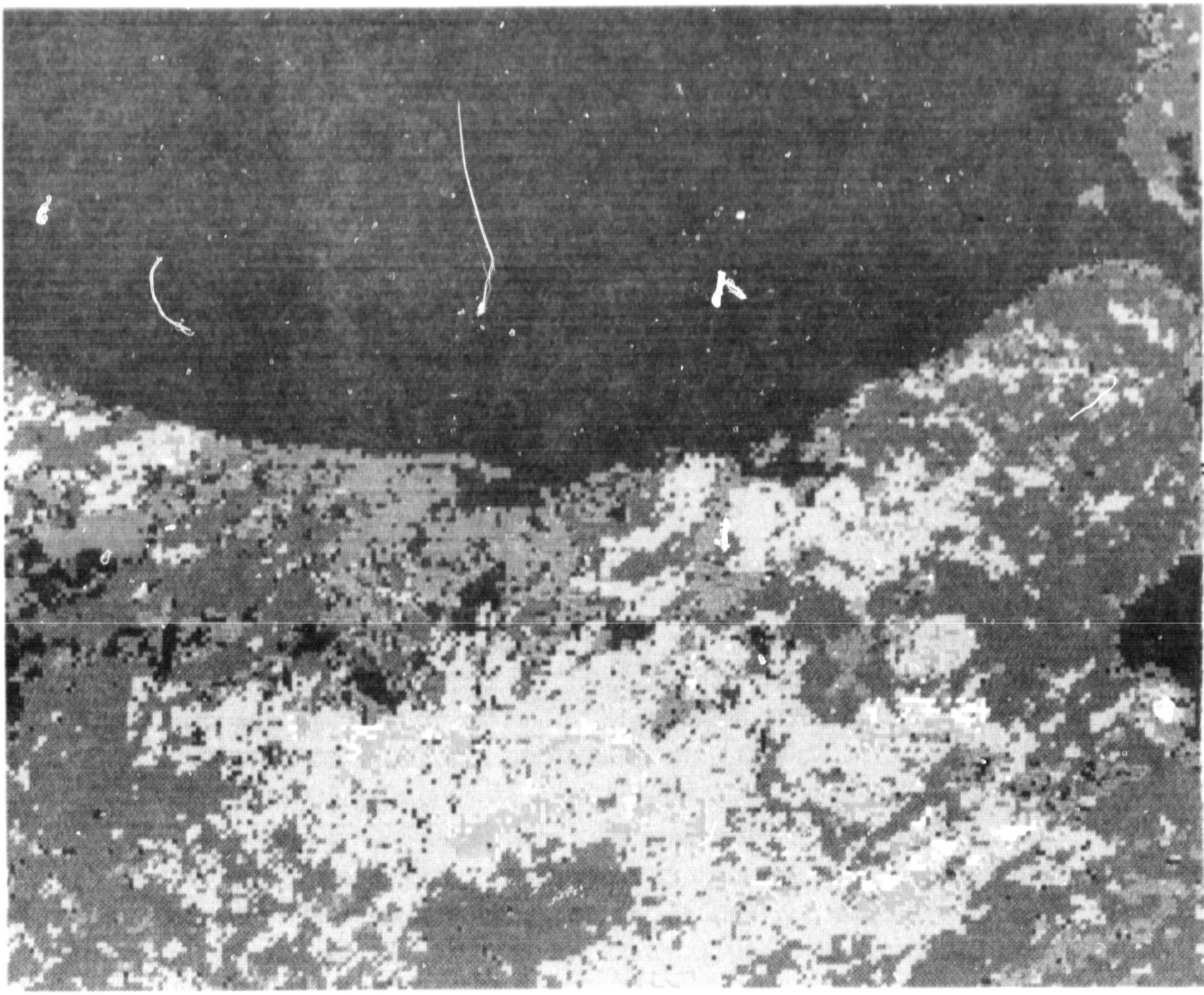

Fig. 20. Example of part of an Colour Ink Jet Plotter printout covering parts of the Medenine test area. Desert patches of the 1972 classification were registered to the 1979 classification. A clean-up procedure was employed to enhance the printout. The classified data were recorded by Landsat-1 on Aug. 8, 1972 and by Landsat-3 on March 19,1979 (205/37). Approximate scale is 1:250 000. (For location of the area please see the inserted frame in Fig. 15).
Classes: Dark green=Oasis and irrigated land, Medium green= Grazed steppe, Light Green= overgrazed (and overcultivated) steppe, Brown=Cultivated land, Dark blue=Water, Light blue=Chott (playa) with bordering chott vegetation, Red=Desert patches existing 1972 and 1979, Yellow=Desert patches generated between 1972 and 1979.
(In the coastal areas the light-blue sometimes indicate shallow water).

a scale range of 1:70 000 to 1:200 000. The results confirm experiences presented in the final report of the French-Tunisian project "A contribution to the ecological analysis of the arid zones of Tunisia with the help of spatial remote sensing data" (CEPE/CNRS 1978). It was concluded that visual analysis of colour composite imagery is a useful tool for the evaluation of seasonal development of vegetation cover (4 to 6 classes of green vegetation cover). It was also concluded that computer assisted mapping of vegetation communities or ecological systems on a large scale (1:50 000) generally appeared not to be easy when using only spectral data, even with a multitemporal approach.

Achieved results in the present study did, however, indicate that approximately the same results can be obtained, regardless of whether thematic maps are generated through interpretation of Landsat false colour composites or through computer processing of Landsat digital data for the given semi-arid and arid environments. Environmental transformation, such as increasing desert patches, indicating recent desertification, can probably be monitored. However, the lowest threshold level at which changes can be monitored using Landsat data is not yet known.

To obtain significant better results than those presented in this report a more sophisticated approach to the problems of analysis and classification is probably needed. Research on the possible role of multitemporal classifications and the use of visible/near infrared (MSS 5/MSS 7) ratios for surveying and monitoring indicators of desertification should be carried out in combination with relevant field data sampling. The possible use of Landsat-3 RBV data with approx. 40-m geometrical resolution as well as the use of factor analysis should be included and tested in such studies.

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