ICW note 1764

February 1987

nota

instituut voor cultuurtechniek en waterhuishouding, wageningen

THE CONTRIBUTION OF LANDSAT DATA TO WATER MANAGEMENT IN TWO ITALIAN IRRIGATION DISTRICTS

M.Sc. Dott.ssa S. Azzali

Nota's van het Instituut zijn in principe interne communicatiemiddelen, dus geen officiële publikaties.
Hun inhoud varieert sterk en kan zowel betrekking hebben op een eenvoudige weergave van cijferreeksen, als op een concluderende discussie van onderzoeksresultaten. In de meeste gevallen zullen de conclusies echter van voorlopige aard zijn omdat het onderzoek nog niet is afgesloten.
Bepaalde nota's komen niet voor verspreiding buiten het Instituut in aanmerking

CONTENTS

1. INTRODUCTION

During the past fifteen years remote sensing methods (CURRAN, 1981; HALL and McDONALD, 1983; COLWELL and HAY, 1979; KAUTH and THOMAS, 1976; MILLER, 1981; JOHNSON, 1981; L.A.C.I.E, 1978; JACKSON, 1982) have been proposed to obtain:

1. Inventories of crop types and acreages in various crops.
2. Crop yield estimates.
3. Detection of crop yield decrement caused by:
   a. diseases or insect infestation;
   b. ununiformity of application of fertilizer and irrigation.

Nevertheless, practical applications dealing with quality, quantity, type of crops and their occurring water stress by LANDSAT images have not, so far, been performed.
The purpose of this research was to assess the feasibility of such methodology and the practical application of this method was tested by means of LANDSAT-images in two study-areas located in the Po valley in Italy (AZZALI, 1985 a, b; AZZALI, 1986; MENENTI et al., 1986).
The developed method called multi-temporal multi-index method is based upon the interrelation between crop phenological cycles and the occurrence of different spectral signatures during the growing stages.
Such approach requires, at first, detailed informations regarding the phenological cycle of the main crops cultivated in the study-areas in the considered years (average crop calendars). Crop phenological informations are much easier to be collected than the crop spectral signatures. Than it's handier to refer crop spectral signatures to vegetative stages. Infact collecting in field the crop phenological informations and combining them with the crop signatures we are able to obtain the temporal variations of crop spectral signatures.
To evidence the different signatures between crops, few vegetation

indices were utilized as: Greenness, Brightness and Transformend Vegetation Index (TVI), which have shown different measurements in detecting the crop phenological stages. Consequently, applying different vegetation indices in a combined manner enhances the opportunities for crop identification. Crop water stress by means of spectral measurements has been studied through about a decade. Near infrared and red wavelenghts for the detection of water content in the vegetation and the ratio, near infrared over red, have been used for the detection of drought stress.
Another approach to assess crop water stress is by measuring canopy temperature by means of thermal infrared thermometry. Such research development was pointed out by a number of literature reviews, of which the most important remain: JACKSON, 1982; PINTER, 1982 and HATFIELD, 1983. Both approaches require crop identification as first step, e.g. by means of different vegetation indices. Then, combining the informations extracted by spectral measurements of near infrared and red wavelenghts with temperature measurements, we will try to assess occurred water stress in crops.
In conclusion, the practical steps to apply the multi-temporal multi-index method for crop discrimination are:

- assessment of average crop calendar for the study area;
- calculation of vegetation index values for the main crops from the available images;
- assessment of crop characteristic interval of applied vegetation indices
- crop discrimination
- assessment of probable water stress occurred to the main cultivated crops

2. DESCRIPTION OF THE STUDY AREAS

2.1. Location of study areas

The application of the multi-index multi-temporal method was tested by means of LANDSAT-images in two study areas which are irrigation districts located in the Po valley, Italy, namely: East Sesia and Grande Bonifica Ferrarese (Fig.1).

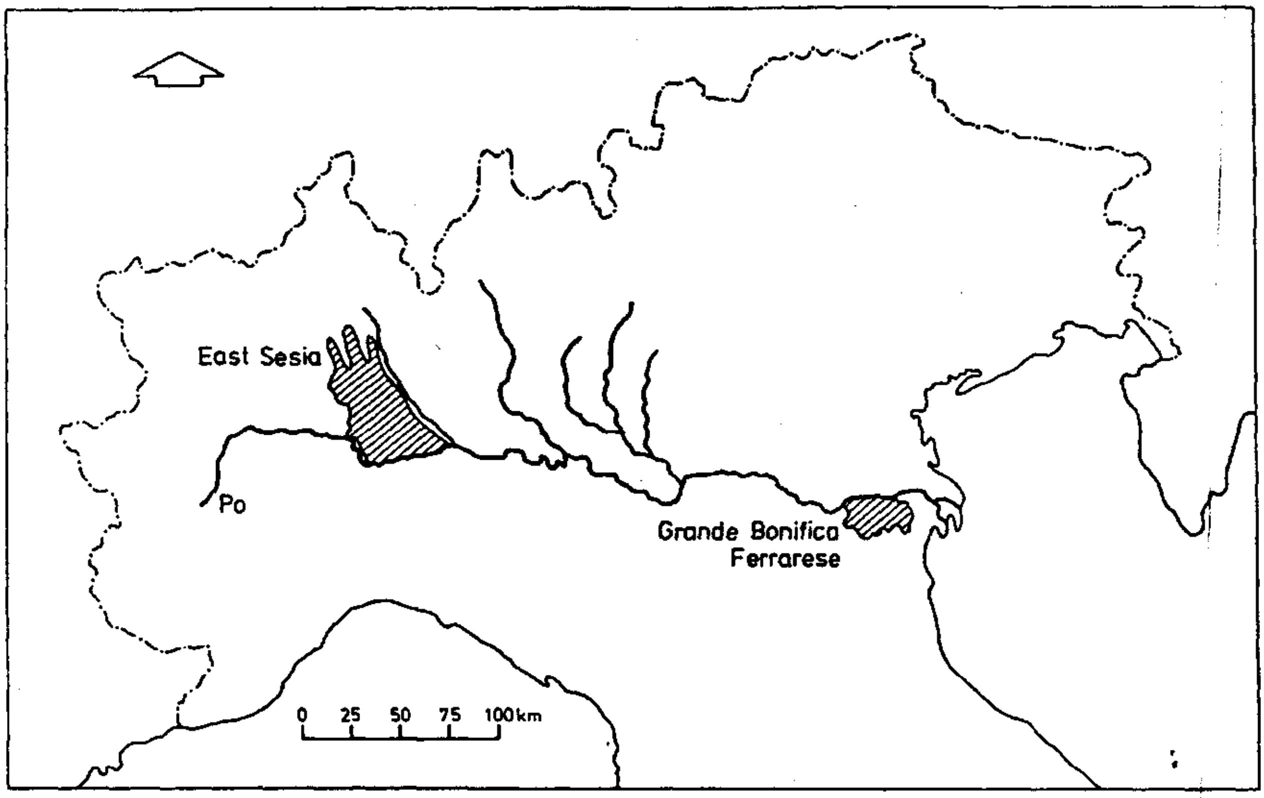

Fig.1. Sketch map of the Po valley, where the two irrigation districts considered in this report are indicated (after AZZALI, 1986)

LANDSAT Multi-Spectral-Scanner images were applied first, while later on we used LANDSAT Thematic-Mapper images.
Table 1 shows the dates when the images, used for this research, were acquired.

Table 1. List of used satellite images

Name irrigation district	Sensor	Frame/Row	Dates
East Sesia	MSS	209/29	22 April,1980 17 August,1980 4 September,1980
	TM	194/28	30 April,1985 3 July,1985 20 August, 1985
Grande Bonifica Ferrarese	MSS	207/29	8 May,1980 28 July,1980 2 September,1980
	TM	192/29	2 May,1985 3 June,1985 22 August,1985

2.2. Irrigation practice in the study areas

The territorial area of East Sesia irrigation district is 210 000 ha while the Grande Bonifica Ferrarese area is 56 150 ha. In both the irrigation districts irrigation water is allocated on fixed rotational intervals on the basis of the hectarages of the growing crops.
Table 2, indeed, shows how the irrigation water charges depend on cultivated crops.

Table 2 . Water charges in East Sesia irrigation district in 1982 (after AZZALI, 1986)

Consumption dependent water charges		
- continuous flow (summer)	$Lit \cdot l^{-1} \cdot s^{-1}$	19 850
- continuous flow (winter)	$Lit \cdot l^{-1} \cdot s^{-1}$	2 500
- district charges	$Lit \cdot ha^{-1}$	14 350
Cultivated area dependent water charges		
- rice	$Lit \cdot ha^{-1}$	254 100
- grassland	$Lit \cdot ha^{-1}$	127 050
- other crops	$Lit \cdot ha^{-1}$	95.280

The irrigation districts control only the actual hecterages of paddy rice fields while for the other crops irrigation water is delivered according to the hectarage declared by farmers. So, irrigation water is allocated just considering the declared crop hectarages without taking into account the actual hectarages and the actual water consumption.

For example, in the East Sesia during 1981 only the 42% of the allocated water diverted into the entire district was actually applied to fields. Moreover, in the Grande Bonifica Ferrarese during 1981 only 13% of the allocated irrigation water was utilized (NIER, 1984).

Such analysis point out that the water allocation criterion applied by the irrigation districts is the maximum guarantee against the risk of crop water stress between two irrigation turns.

The surplus of irrigated water cannot be allocated in a more flexible manner, one of the reasons being the insufficient information on actual hectarage. Mereover, the cultivated area dependent water charges do not promote water management practices aiming at minimum water consumption.

An improved allocation of irrigation water could be achieved by means of a satellite based control procedure to provide the exact information on crop types, cultivated area and probable water stress. This would make feasible a more demand-oriented allocation procedure. The semi-operational test of the multi-temporal multi-index method will help to understand the shortcomings in the irrigation districts.

Furthermore, analysing the current irrigation season, an improved irrigation strategy can be set up for the coming season.

3. APPLIED UTILIZED VEGETATION INDICES

The two different sensors MSS (Multi-Spectral-Scanner) and TM (Thematic Mapper) on board the LANDSAT satellite measure radiance data in arbitrary units.
Table 3 is summarizing the available bands and their spectral coverage of MSS and TM sensors.

Table 3 : Bands and spectral ranges of MSS and TM sensors

Bands	MSS	Bands	TM
n.	(μm)	n.	(μm)
4	0.5-0.6	1	0.45- 0.52
5	0.6-0.7	2	0.52- 0.60
6	0.7-0.8	3	0.63- 0.69
7	0.8-1.1	4	0.76- 0.90
		5	1.55- 1.75
		7	2.08- 2.35
		6	10.40-12.50

The raw data in digital counts should be converted to scientific units such as reflectance in order to compare data between images taken on different dates and/or by different sensors.
The scientific unit used in this research is reflectance which can be calculated from radiance value as the ratio of the radiant energy reflected to the total that is incident upon a surface.
Reflectance unit values were used in three vegetation indices formulas respectively greeenness, brightness and TVI which are utilized for crop discrimination in the study-areas.
In order to calculate the greenness and brightness formula coefficients,we point out that such coefficients are strictly correlated with the type of soils present in the area object of study (KAUTH and THOMAS,1979; HALL, 1984).Therefore we have calculated the new coefficients for each sensor (MSS and TM) and for the most representative soil associations present in the two irrigation districts by computing a new soil line (AZZALI,1985 b).

The calculated formulas for MSS and TM sensors are the following ones:

MSS

$$Greenness = -0.085*R4-0.159*R5+0.058*R6+0.327*R7 \quad (1)$$

$$Brightness = 0.068*R4+0.124*R5+0.146*R6+0.29*R7 \quad (2)$$

TM

$$Greenness = -0.144*R1-0.173*R2-0.262*R3+0.214*R4-0.159*R5-0.339*R7 \quad (3)$$

$$Brightness = 0.151*R1+0.264*R2+0.354*R3+0.415*R4+0.601*R5+0.499*R7 \quad (4)$$

Furthermore in this study, a third vegetation index, called TVI,was used and expressed by the following formulae:

for MSS

$$TVI = \left[\frac{R7 - R5}{R7 + R5} + 0.5\right]^{1/2} * 100 \quad (5)$$

for TM

$$TVI = \left[\frac{R4-R3}{R4+R3} + 0.5\right]^{1/2} * 100 \quad (6)$$

These three vegetation indices are described in details by: KAUTH and THOMAS, 1976; JACKSON et al., 1983; MILLER, 1981; ROUSE et al., 1973.

4. CROP CALENDARS FOR THE TWO STUDY AREAS

4.1. Importance of crop calendar

An information for maximizing the effectiveness of multi-temporal interpretation of LANDSAT images for inventoring and monitoring croplands in areas of diverse cropping is the crop calendar.
The crop calendar indicates the range of dates of planting, of different phenological stages and harvesting. Combining the crop calendar (progressive change of the crop from a phenological stage to the following one) with the different crop signatures, crops can be discriminated from each other. Then, crop calendar is an essential information to describe the crop cycle; in addition, the crop calendar enables a prediction of the optimum date for identification of the main crops in the test areas.

4.2. Crop calendar year 1980

The informations utilized for the preparation of the 1980 crop calendars for East Sesia and Grande Bonificazione Ferrarese irrigation districts were provided from the following sources:

1. Informatore Agrario (1980, 1981): phenological and meteorological data in 1980.
2. CLERMONT and MENENTI (1984): 1980 average crop calendar meaningful for the entire Po valley area.

No ground control areas were taken into account.
Then, for the East Sesia irrigation district,the crop calendar shown in Fig. 2 was prepared on the basis of growing stages defined as:

stage s - seeding stage

stage 1 - initial stage : germination and early growth when the soil surface is not or hardly covered by the crop (ground cover 10%)

stage 2 - crop development stage: from end of initial stage to attainment of (effective) full ground cover (ground cover= 70-80%)

stage 3 - midseason stage : from end of attainment of effective full ground cover to time of start of ripening as indicated by discolouring of leaves (beans) or leaves falling off (cotton).
For some crops this may extend very near to harvest (sugar-beet)

stage 4 - late season stage: from midseason stage untill full maturity or harvest

Definitions of these phenological stages (excluded for stage s) are the same applyed by DOORENBOS and PRUITT, 1977.

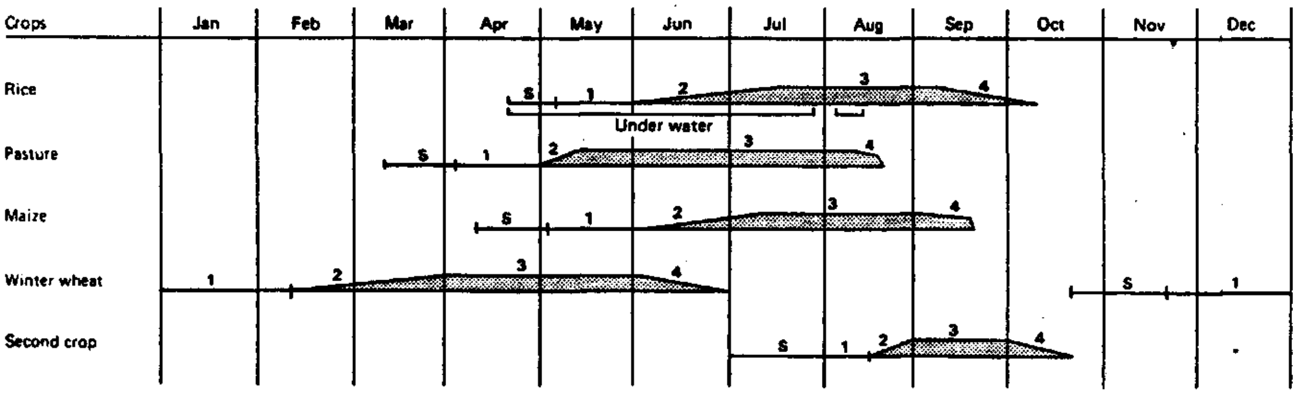

Fig. 2. Crop calendar of main crops grown in East Sesia and Villoresi (after Clermont and Menenti,1984)

For Grande Bonifica Ferrarese irrigation district the crop calendar shown in Fig.3 was prepared on the basis of the following phenological stages:

1. for annual crops as winter wheat, sugar beet, maize, pasture and second crop:

   s = seeding
   0 = establishment
   1 = vegetative
   2 = flowering
   3 = yield formation
   4 = ripening

Definitions of the stages 1 till 4 of annual crops are the same applied by DOORENBOS and KASSAM (1979).

2. for perennial crops as alfalfa and fruit trees:

   a = reaching full growth (for alfalfa) or full leaves development (for fruit trees)

   b = full growth

   c = ending of grass growing season (alfalfa) or turning colour of fruit trees leaves

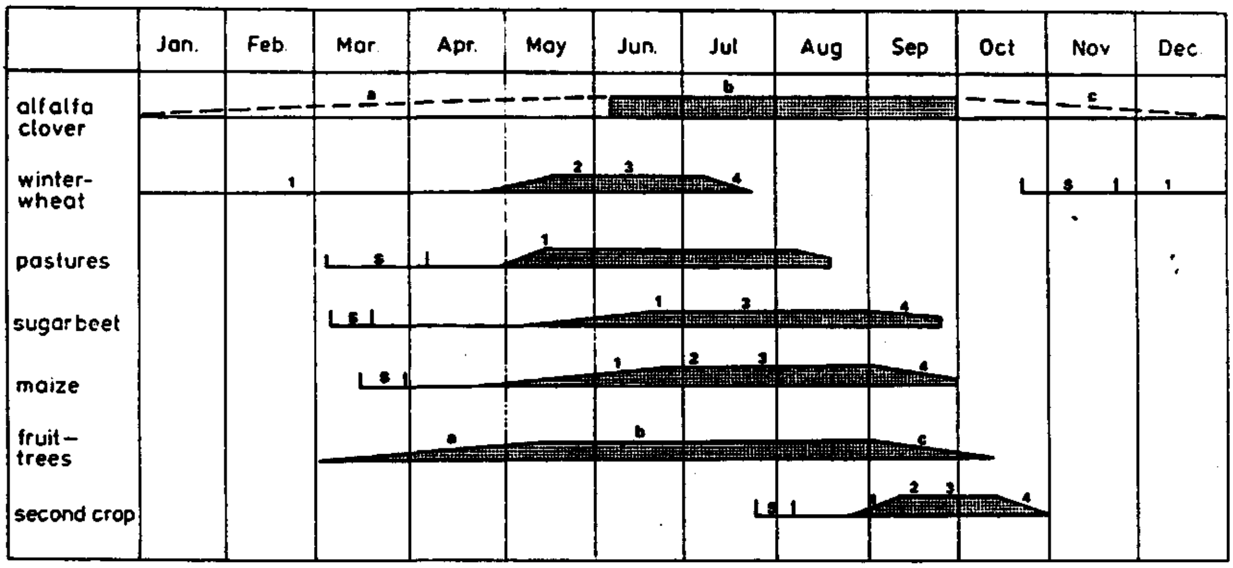

Fig. 3. Crop calendar for the year 1980 concerning the main crops cultivated in Grande Bonifica Ferrarese; for definition of growth stages see the text (after AZZALI, 1985b)

4.3. Crop calendar year 1985

In the early summer 1985,the results of the multi-temporal multi-index method (AZZALI,1985a, b) showed that the knowledge of crop calendar variability within a particular area is the core information to discriminate the crops from each others by means of satellite LANDSAT images.

Then, considering the crop year 1985, in both the irrigation districts several field plots have been selected and agronomic informations have been recorded on the actual cultivated crops in September 1985.

Table 4 shows a list of the ground truth plots located in the East Sesia irrigation district.

Table 4. Ground truth plots in the East Sesia irrigation district (after AZZALI, 1986)

Code	Farm	Cultivated crops			
		rice	corn	grass	winter wheat
1,12	Banca popolare Novara	x		x	
2	Sallustia-Gamaletta	x			
3	Zumaglini-Gallina	x			x
4	Marangana	x		x	
5	Ponzana	x	x		
6	Mirabello	x			
7	Bronzina	x			
8	Cineroli-Biandrate	x	x		
10	Pregalbe Inf.	x			
11	Bertoldo			x	
14	Magni	x	x	x	
15	Prati Grassi			x	
16	Vigone G.		x		
18	Posta	x	x		
19	Magnana		x		
22-23	Baruffaldi		x		
24	Santa Rosa		x		

For each plot a form was filled in, including agronomic informations on crops as dates of occurrence of phenological stages, irrigation management, etc. An example of such form is shown in Fig.4.
The same procedure was repeated in the Grande Bonifica Ferrarese irrigation district. Table 5 shows the list of selected farms and ground truth plots regarding the cultivated crops in that area.
The collected informations showed up a high variability in time of the same phenological stage and the same crop.
By using the method illustrated by MENENTI et al.,1986, we were able to calculate the average duration of each phenological stage. Such duration is defined as the interval within which 80% of the observed area has reached a certain phenological stage.
By calculating the duration of each phenological stage for each crop, the average crop calendar was set on for East Sesia (Fig. 5) respectively Grande Bonifica Ferrarese (Fig. 6) irrigation districts.
In these crop calendars the phenological stages have been coded and defined as follows:

semina	germina-	accrescimento		fioritura	formazione	matura-	raccolta
		vegetativo					
	zione	primo	ultimo	(2)	spiga	zione	
	(o)	stadio	stadio		(3)	(4)	
		(1a)	(1c)				

<u>Come usare le schede del ciclo vegetativo delle colture.</u>

anno dell'indagine:1985

Indicare le date (medie per l'intera area di studio) d'inizio e fine degli stadi fenologici, indicati in ciascuna scheda del ciclo vegetativo delle colture.
Per esempio, per la coltura frumento invernale:

semina	germinazione	etc.
metà ott.-nov.	nov.-dicembre	....

Come maturazione (4) si intende il cambiamento di colore della pianta da verde a giallo. Si può indicare dapprima il cambiamento da verde a giallo della spiga e poi quello dell'intera pianta.

Fig. 4. Example of form for phenological stages of winter wheat

Table 5. Ground truth plots in the Grande Bonifica Ferrarese irrigation districts (after Azzali, 1986)

Code	Farm	Crops											
		winter wheat, barley	corn	rice	sugar beet	orchard	soy-beans	toma-toes	water melon	straw-berry	poplar trees	sun-flowers	vine-yards
1	Consorzio Volontario Produttori Agricoli (Bosco)	x	x	x			x		x				
2	Cavazzini Giancarlo (Le Cóntane)	x		x			x		x				
3	Scalambra (Dosso Malea)	x	x		x								
4	Pomposa S.R.L. S. Francesco	x					x						
5	Crepalda Nuova (Serravalle)		x	x			x						
7	Società Bonifiche Terreni Ferraresi	x	x	x	x		x						
8	Società Belvedere - Dante (Massa Fiscaglia)	x		x	x		x						
9	Guidi Giuliano (Bosca)				x		x	x				x	
9bis	Guidi Giuliano (Malea)	x			x								
9bis	Guidi Giuliano (Varano)					x							
10	Scalambra (Pomposa)	x	x		x		x	x					x
11	Agrital (Italba)	x	x				x		x				
12	Mazzoni (Migliaro)	x	x	x		x					x		
13	Zanzi S.R.L. (Italba)		x							x			
14	Moraro										x		
15	Capatti	x	x		x	x	x				x		

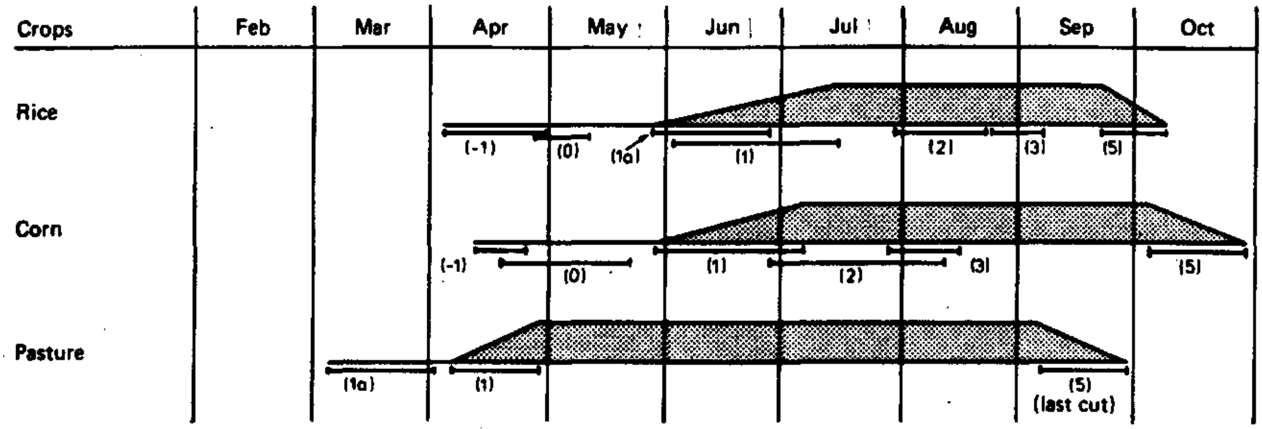

Fig. 5. Average crop calendar for the year 1985 of the main crops cultivated in East Sesia; symbols and numbers are referring to the text

(-1)	seeding stage
(0)	emergence
(1)	full cover
(1a)	tillering (only for rice)
(1c)	head development
(2)	flowering
(3)	yield formation
(3)	milk ripening (only for grains)
(4)	full ripening
(5)	harvest

Concerning the Grande Bonifica Ferrarese irrigation district (crop calendar Fig. 6) we did not include in the crop list strawberry, sunflower, vineyard,tomatoes and watermelon, being those crops not enough representative in that area. Furthermore, in Fig. 6 no phenological stages of the above list is considered for poplar and orchard, but the calendar indicates leaves development (a), full vegetative cover (b) and leaves loss (c).

Concerning the East Sesia irrigation district, we did not include winter wheat in the crop calendar of Fig. 7, being that crop not anymore important in that area.

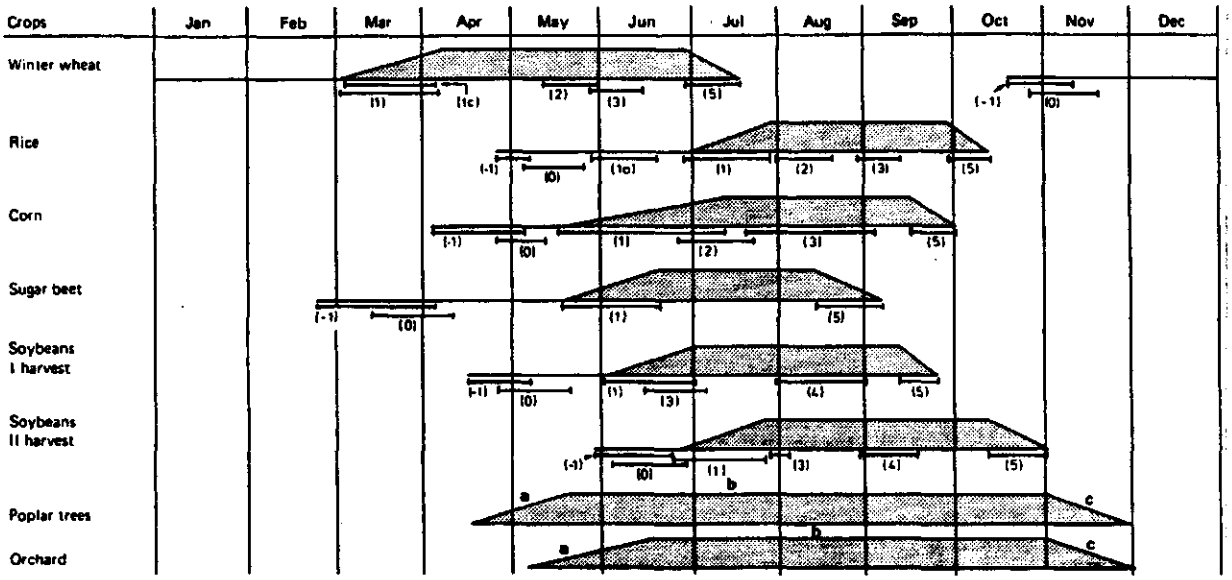

Fig. 6. Average crop calendar for the year 1985 of the main crops cultivated in Grande Bonifica Ferrarese; symbols and numbers are referring to the text

4.4. Changes of the agricultural investments within five years in the study areas

Remarkable variations in the types of cultivated crops have occurred between year 1980 and 1985 in East Sesia and Grande Bonifica Ferrarese irrigation districts. In particular, in 1985 and in East Sesia territory winter wheat has been replaced by corn and rice, which production seems,nowadays,more remunerable.

In the Grande Bonifica Ferrarese territory alfalfa and haygrass have been replaced by cash crop as soybeans.

5. APPLICATION OF THE MULTI-INDEX MULTI-TEMPORAL METHOD TO THE TWO TEST AREAS

5.1. Interpretation of LANDSAT-MSS images (1980)

5.1.1. Reference data

For both the irrigation districts only statistical data (ISTAT data,year 1980) were available on the cultivated area for each crop. ISTAT data were applied to the cultivated areas referred to the provinces, which territories do not coincide with the irrigation districts with a province being either larger or smaller than a irrigation district.
Table 6 shows the ISTAT data 1980 referred to the hilly and flat agricultural areas of Novara province, which areas represent mainly the part of East Sesia irrigation district shown in Photo 1, Appendix 2.

Table 6. Cultivated area as percentage of the agricultural hilly and flat areas of Novara province for five main crops cultivated in East Sesia, as estimated on the basis of ISTAT data collected for 1980 farming year (after ISTAT,1982)

CROP	Cultivated area in Novara province (%)
rice	32.4
haygrass	27.0
corn	24.3
pasture	6.0
winter wheat	6.0

The portion of the East Sesia irrigation district shown in the considered LANDSAT-MSS images (Photo 1, Appendix 2) occupies a big part of the agricultural flat and hilly areas in Novara province, which means that the reference ISTAT data closely relate to the crop cultinated area as estimated with the MSS.
Table 7 shows the statistical ISTAT data 1980 referring to Grande Bonifica Ferrarese irrigation district.

Table 7. Cultivated area as percentage of the total agricultural area of Ferrara province for 10 main crops cultivated in Grande Bonifica Ferrarese, as estimated on the basis of ISTAT data collected for the 1980 farming year (after ISTAT,1982)

CROPS	cultivated area relative to Ferrara province (%)
winter wheat	23.0
haygrass	14.5
alfalfa	0.03
pasture	
corn	8.0
sugar beet	20.0
trees	11.9
rice	2.8
tomato	1.3
horticultural crops	4.6

These data give the crop areas in the entire province of Ferrara, while the Grande Bonifica Ferrarese irrigation district occupies only the 27% of the territorial area of Ferrara province.
Moreover, the areal distribution of certain crops inside the irrigation district is not homogeneous all over the territory of Ferrara province.

5.1.2. Typical greenness, brightness and TVI values of crops

Lack of ground control plots in the year 1980 suggested the use of reference reflectance measurements which were collected in the available literature for the same crops cultivated in East Sesia and Grande Bonifica Ferrarese.
From the collected reflectance measurements, we calculated the values of the vegetation indices (Greenness, Brightness and TVI) corresponding to the characteristic growing stages and utilizing the formulas (1), (2) and (5). Therefore, by relating the characteristic vegetation index values to the crop calendars (Figs.2-3), the progression of the vegetation indices was obtained as function of time. Tables 8, 9 and 10 shows the typical values respectively of greenness,

brightness and TVI from April till September regarding those crops cultivated in the East Sesia and Grande Bonifica Ferrarese irrigation districts.

5.1.3. Crop characteristic intervals of vegetation indices

Crops present in tables 8, 9 and 10 are the main crops cultivated in the study areas in the year 1980. A characteristic interval for each crop and for each vegetation index was defined having as two limits (upper and lower limits) the mean vegetation index value for each crop in each month +10% respectively -10% of the typical value. The monthly characteristic interval for each crop was compared with vegetation index value of the other crops to detect which interval (within different vegetation indices, within different months) was able to discriminate the crops from each others.
Figures 7 and 8 show the scheme of possible crop discriminations by means of the multi-temporal multi-index method for the available dates of images acquired in the two study areas.

Table 8. Typical Greenness values of a number of crops during the period April through September, as obtained from literature data. For explanation of symbols, see 'List of codes' (after AZZALI, 1985b)

Months	A_1	A_2	B_3	C_1	D_1	E_1	E_4	F_1	G_1	G_2	H_1	I_1	I_2	I_4	L_1	M_1	N_1
April	31.3	27.6	0	13	14	10				-5	-5		-3	-1	4.3		
May	37	22	10	13	14.3	12.9	27		23.4	3.5	-4			5.2	19.5		
June	23.7	17.9	20	18.5	20.5	21	29		24.9	25	10	32		20	27.6		
July	4	0.4	28	21	18.6	11.9	32(10)	5	33.5	30	-3	32		31	.25.5		16.2
Aug.			20	21	15	9.5	30(10)	25	30	29	4	29.2		18.6	13.6	9.7	
Sept.			18.6	17	10		20(10)	30	20.5	28.6			17	17.1		10.8	18.32

Table 9. Typical Brightness values of a number of crops during the period April through September, as obtained from literature data. For explanation of symbols, see "List of codes" (after Azzali,1985 b)

Months	A_1	A_2	B_3	C_1	C_2	D_1	D_2	E_1	E_4	F_1	G_1	G_2	H_1	I_1	I_4	L_1	M_1	N_1
April	45.2	54.8	25.6	66		57.9		41				36.5	35.5		46	53.6		
May	45.6	59	25.6	66.7	57	62.6	61	59.5	50		49.8	53.5	50.7		49	62.1		
June	32.9		30	67	53	64.5	61	64.3				58	53.1	57	62.4	65		
July			36	60.7	50	65.9	61	52.1	56	48	60.6	67.4	35	56	61.9	63.8		37.2
Aug.			40.5	52.2	55	46.2	57	45.5	53(49)	55		65	36.2	66	55.2	62.9	35.4	
Sept.			52.6		61		49			65	50	62.7			48.6		36.1	42.1

Table 10. Typical TVI-values of a number of crops during the period April through September, as obtained from literature data. For explanation of symbols, see "List of codes" (after Azzali, 1985b)

Months	A_1	A_3	A_4	A_5	B_1	B_2	C_3	C_4	D_3	E_2	E_3	F_1	G_3	I_1	I_3	I_5	L_2	M_1	N_1
April	1.16	1.15	1.17	0.89	0.70		0.95	0.96	0.5				0.79		0.75				
May	1.13	1.11	1	0.94	0.76	0.5	0.98	0.99	0.95	1			0.93	0.85	0.85	0.85	0.91		
June	1.05	1.03			1.06	0.89	0.95	0.94	1.13	0.99	0.71	0.85	1.05	0.96	1.00	1.03	0.89		
July	0.75				1.13	1.01	0.97	0.95	1.12	1.04	1.13	1.00	1.10	0.96	1.08	1.18	0.92		1.17
Aug.					1.13		0.97	0.96	1.02			1.10	1.08	0.95	1.00	1.17		0.93	
Sept.					0.89								1.04	0.80	0.71	1.03		0.92	1.13

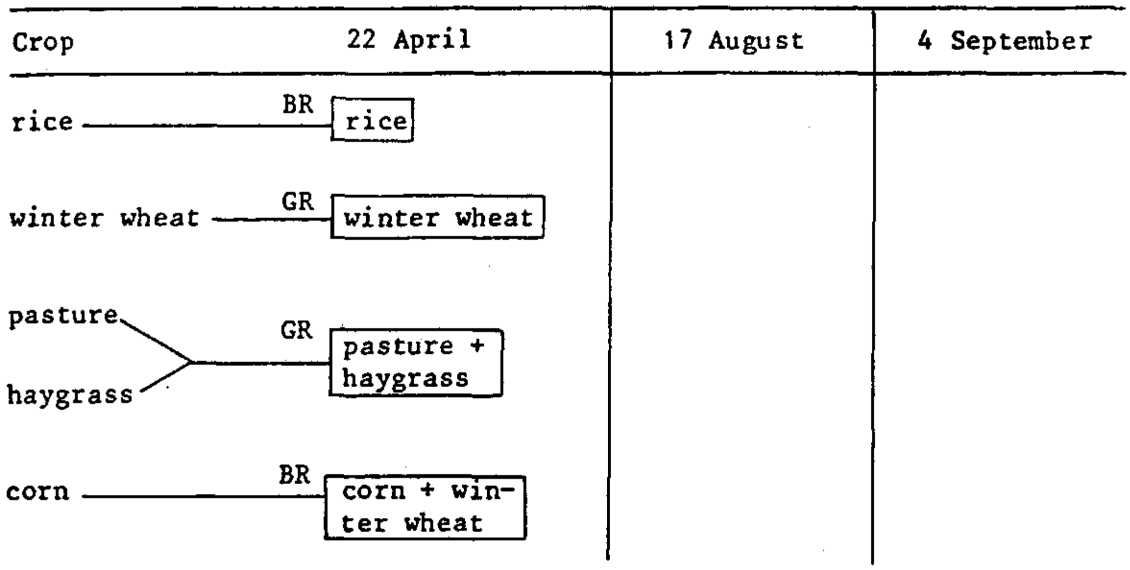

Fig. 7. East Sesia, image 209.29. Available dates : 22 April, 17 August and 4 September, 1980. Crop discrimination by the combained use of three vegetation indices (after Azzali, 1985b)

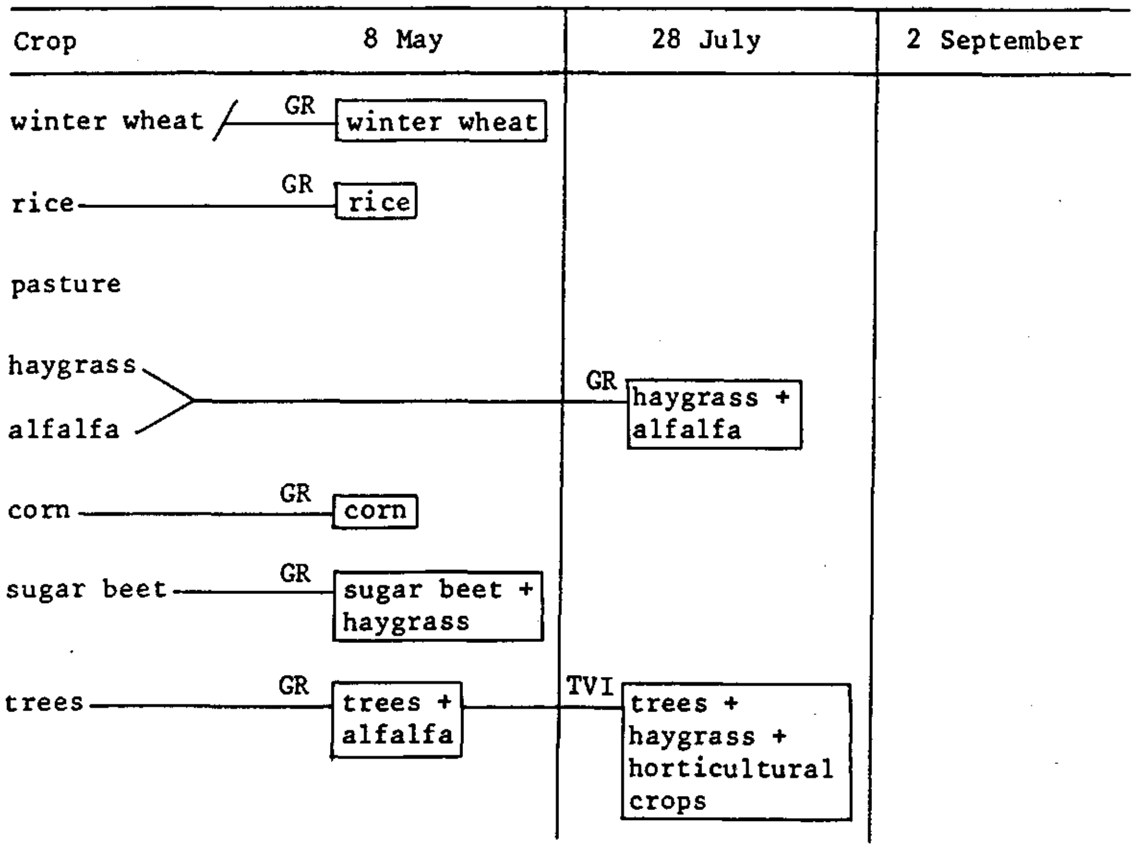

Fig. 8. Grande Bonifica Ferrarese, image 207.29. Available dates: 8 May, 28 July and 2 September, 1980. Crop discrimination by the use of three vegetation indices (after Azzali, 1985b)

Tables 11 and 12 show the characteristic crop intervals required to apply the discrimination schemes of figures 7 and 8 ,for East Sesia and Grande Bonifica Ferrarese irrigation districts.

Table 11. Characteristic crop interval (a,b) of greenness, brightness and transformed vegetation index; East Sesia year 1980 (after Azzali, 1985 b)

		APRIL	
CROPS	Greenness	Brightness	TVI
rice		(16,36)	
haygrass	(12,16)		
pasture			
corn		(42,51)	
winter wheat	(27,33)		

Table 12. Characteristics crop interval (a,b) of greenness, brightness and transformed vegetation index; Grande Bonifica Ferrarese, year 1980 (after Azzali, 1985 b)

CROPS	May			July
	GR	BR	TVI	GR
winter wheat	(25,43)			
alfalfa				
haygrass				(17,21)
corn	(3,7)			
sugarbeet	(10,16)			
trees	(17,23)			
rice	(-4,0)			

5.1.4. Results of crop discriminations

Comparing the values of crop cultivated area as percentage of the total territorial area (Istat data) and the estimates obtained by applying the discrimination schemes of figures 7 and 8, we remark that:

1) In the East Sesia irrigation district (table 13) the multi-temporal multi-index method achieved rather good estimates, even though there is, clearly, an overestimation of haygrass and pasture cultivated areas.
2) In the Grande Bonifica Ferrarese irrigation district (table 14) four out seven crops were well estimated, while haygrass, alfalfa and trees were overestimated.

Table 13. Crop cultivated area as percentage of the total territorial area estimated from reference Istat data respectively multi-temporal multi-index method; East Sesia,year 1980

	Istat 1980	multi-temporal multi-index method
RICE	32.4	29.6
CORN	24.3	22.0
WINTER WHEAT	6.0	6.5
HAYGRASS+ PASTURE	33.0	47.9

Table 14. Crop cultivated area as percentage of the total territorial area estimated from reference Istat data respectively multi temporal multi-index method; Grande Bonifica Ferrarese, year 1980

	Istat 1980	multi-temporal multi-index method
WINTER WHEAT	23.0	20.5
HAYGRASS+ ALFALFA	14.5	21.5
CORN	8.0	9.2
SUGAR BEET	20.0	16.1
TREES	11.9	16.1
RICE	2.8	3.3

5.2. Interpretation LANDSAT-TM images (1985)

5.2.1. Crop discriminations by means of TM images

Reflectance and vegetation index values for each crop in the three available images have been obtained for every ground control plot. To consider the variability of each crop due to different seeding date, varieties, management, etc., we calculated an interval of vegetation index characteristic values for each crop. Following the method described by MENENTI et al., 1986, crop classification was performed assigning a characteristic interval for each crop and for the considered vegetation indices (TVI, greenness and brightness) having as two limits (upper and lower limits) the mean vegetation index value for each crop (mean value calculated from vegetation indices measurements extracted from several ground control areas) +1.5 respectively -1.5 of its standard deviation. Such characteristic interval, which for better understanding will be called "method a" was calculated for each available image.

Figures 9 and 10 show the scheme of possible crop discriminations by means of the multi-temporal multi-index method assigning the characteristic interval "method a".

CROPS	30 APRIL	3 JULY	20 AUGUST
RICE	TVI		
PASTURE+ HAYGRASS	TVI		
CORN	TVI		

Fig. 9. Discrimination scheme; East Sesia

CROPS	2 MAY	3 JUNE	22 AUGUST
RICE		BR	
WINTER WHEAT	TVI		
TREES	TVI		
CORN	no discrimination		
SUGAR BEET	no discrimination		
SOYBEANS I HARVEST	no discrimination		
SOYBEANS II HARVEST	no discrimination		

Fig. 10. Discrimination scheme; Grande Bonifica Ferrarese

Tables 15 and 16 show the discrimination crop intervals by the three indices and the crop cultivated area (percentage of the TM-sub-image area) calculated using the discrimination schemes of Figs.9-10 for East Sesia and Grande Bonifica Ferrarese irrigation districts.

Table 15. TVI characteristic crop interval "method a" (a,b); crop cultivated area (as percentage of TM-sub-image area) estimated by means of TVI; East Sesia, April 1985.

CROPS	TVI	AREA
	(/)	(%)
RICE	(56-67)	20.5
HAYGRASS PASTURE	(106-112)	5.5
CORN	(68-83)	32.0

Table 16. Characteristic crop interval " method a" (a,b) of TVI, brightness and greenness; crop cultivated area (as percentage of TM-sub-image) estimated by means of three vegetation indices; Grande Bonifica Ferrarese, year 1985

CROPS	APRIL				JUNE				AUGUST		
	TVI	%	BR	GR	TVI	BR	%	GR	TVI	BR	GR
RICE						(15-31)	5.5				
WINTER WHEAT	(104-109)	18.0									
CORN			no discrimination								
SUGAR BEET			no discrimination								
TREES	(88-103)	15.0									
SOYBEANS I HARVEST			no discrimination								
SOYBEANS II HARVEST			no discrimination								

5.2.2. Improving crop classification

Not all the ground control pixels of the considered crops in East Sesia were included in the characteristic interval "method a" ($I+1.5*\sigma m$). Then, for both the irrigation district an attempt for a better crop classification was performed.

-EAST SESIA

Table 15 shows that with just one image (30 April,1985) crop classification was performed by means of vegetation index TVI in East Sesia irrigation district. Indeed, that date is the best one to discriminate rice from corn and from grass because those crops have achieved three different stages (flooded field for rice, seeding stage for corn and full ground cover for grass).
Nevertheless, the crop classification of table 15 adopting the characteristic interval "method a" leaves unclassified part of the cultivated areas of the main considered crops. The best classification was achieved when the characteristic interval for each crop is calculated following this procedure (method b):

1) interval lower limit = the lowest mean value of TVI for a certain crop extracted by the ground control plots minus 0.75 * standard deviation
2) interval upper limit = the maximum mean value of TVI for a certain crop extracted by the ground control areas plus 0.75 * standard deviation.

Results of crop classification according to the characterisitic interval "method b" is shown in table 17.

Table 17. TVI characterisitic crop interval "method b" (a,b); crop cultivated area (as percentage of TM-sub-image area) estimated by means of TVI; East Sesia, April 1985

CROPS	TVI	AREA
	(/)	(%)
RICE	(50-67)	37.3
HAYGRASS PASTURE	(102-112)	7.2
CORN	(71-81)	31.8

The rice ground control plots unclassified by the characteristic interval "method a" (values of TVI between 56 and 67) were succesfully classified by means of the characteristic interval "method b" (values of TVI between 50 and 67). From the comparison between the results of rice classification in table 15 and 17, we remark that the TVI characteristic interval "method a" of rice was able to detect part of the total cultivated area discriminated by means of TVI characteristic interval "method b". Then a wider characteristic interval gave better classification because those TVI values of the rice field plots, represented non homogeneous objects which do not belong to the same normal parent distribution and such objects were partly discriminated by the TVI characteristic interval "method a" for rice. The variability of TVI values, in this case, should mostly be attributed to different water depths in the rice basins.
High variability of TVI values in the grass-pasture fields, due to the presence on the same date of both fully grown vegetation and recently cutted grass, was also recorded from ground control plots. Because of such high TVI variability, the TVI characteristic interval "method a" was unable to classify the entire grass ground control plots while the TVI characteristic interval "method b" achieved a better classification. In conclusion, in the East Sesia irrigation district crop classification according to the application of the crop characteristic interval "method b" gave the best discrimination of the three main crops by means of TVI in TM-image of 30 April, 1985.

-GRANDE BONIFICA FERRARESE

In the Grande Bonifica Ferrarese three out of seven crops were discriminated by applying the crop characterisitc intervals "method a". Those three crops were rather easy to discriminate in the TM-images of 2 May and 3 June, 1985, because, according to the crop calendar of Figure 6, winter wheat had already reached full ground cover, trees were gradually reaching the full leaves development stage and rice fields were flooded. Corn, sugar beet and soybeans (spring crops), on the contrary, were not so easy to discriminate.
Nevertheless, discrimination of the spring crops can be performed by means of the multi-temporal multi-index method assigning the characteristic interval calculated with "method a" where the standard deviation is multiplied by 0.75 instead than by 1.5.
Figure 11 shows the new discrimination scheme for the main crops in Grande Bonifica Ferrarese.

CROPS	2 MAY	3 JUNE	22 AUGUST
RICE		BR rice	
WINTER WHEAT	TVI winter wheat		
TREES	TVI trees		
CORN			BR corn + trees
SUGAR BEET		TVI sugar beet + trees + w.wheat	
SOYBEANS I HARVEST		GR soybeans I + corn + soy= beans II harv.	
SOYBEANS II HARVEST			TVI soybeans II harvest

Fig. 11. Discrimination scheme; Grande Bonifica Ferrarese

Table 18 summaries the crop classification in Grande Bonifica Ferrarese using the discrimination scheme of Fig.11 and assigning the characteristic interval "method a" to winter wheat, rice and trees while to corn, soybeans and sugar beet was assigned a characteristic interval having as two limits the mean vegetation index value for each crop +0.75 respectively -0.75 times his standard deviation.

Table 18. Characteristic crop interval "method a" (a,b) of greenness, brightness and TVI for winter wheat, rice and trees; smaller characteristic crop interval (a,b) of greenness, brightness and TVI for corn, soybeans and sugar beet; crop cultivated area (as percentage of TM-sub-image area) estimated by means of the multi-temporal multi-index method; Grande Bonifica Ferrarese, year 1985

CROPS	MAY				JUNE						AUGUST			
	TVI	%	GR	%	TVI	%	BR	%	GR	%	TVI	%	BR	%
Rice							(17-31)	5.5						
Winter wheat	(105-108)	12.8												
Corn													(30-32)	23.1 23.1-15= 8.1
Sugar beet					(98-107)	43.8 43.8-15.9-15=12.9								
Trees	(91-101)	15.0												
Soybeans I Harvest									(119-124)	35.6 35.6-8.1-0.1=27.4				
Soybeans II Harvest											(108-110)	0.1		

5.2.3. Few remarks on the characteristic intervals used for crop discrimination with TM-images

The constraints on which a good crop classification depends, are:

1) Time of the year in which cultivated crops grow
2) Phenological variability within the same stage for a given crop and area
3) Availability of timely satellite images.

In the East Sesia, for example, the three main crops (rice, corn and grass) showing very different phenological stages (point 1) on the TM-image of 30 April, 1985 (perfect timeless, point 3), can be discriminated very well on that date and, notwithstanding phenological variability of rice and grass (point 2), crop discrimination and classifications achieved the best results by means of one vegetation index (TVI). In the Grande Bonifica Ferrarese, on the other hand, spring crops showed overlapping phenological stages (fig.8) and some were virtually coincident with one another (corn-soybeans) given the available images. In this case, the three above written constraints were influencing negatively the performance of spring crops discrimination. Nevertheless, the constraints were overcome by the multi-temporal multi-index method which gave rather good discrimination.

6. FROM METHODOLOGY TO OPERATIONAL APPLICATIONS

6.1. Actually available and suitable LANDSAT images

The application of LANDSAT data to crop monitoring does in principle benefit from high temporal resolution. As table 19 shows, however, the percentage of actually available images, i.e. those present in the Earthnet archive, and of suitable images, i.e. those available within the period most suited to crop identification (Azzali, 1985 b) are relatively low. In 1985, for example, only 17.5% of overpasses gave suitable images for our purpose. It should also be noted that 1985 was the best year in the time span 1980-1985 (Table 19). We deem 3 suitable images essential to warrant feasibility of the here described application. Table 19 shows that applications requiring 3 suitable images per year except 1983. Anderson (1986) underscored the commercial potential of crop monitoring by means of LANDSAT applications requiring 4 and 5 suitable images per year. Table 19 shows that such applications would not be operationally reliable, since five MSS suitable images were available for only two years out of six for both irrigation districts.

Table 19. Number of available and suitable images, compared with theoretically possible number of satellite overpasses from April till September, for the two irrigation districts from 1980 through 1985 (after Azzali, 1986)

Year	Path/row	Sensor	Station	Over-passes	Available images		Images cloud free in 4 quadrants		Images cloud free in the relevant quadrants		Suitable images in relevant quadrants from April to Sept.		Number of required images for the investigation
					number	% of total	number	% of total	number	% of total	number	% of total	
GRANDE BONIFICA FERRARESE													
1980	206/29	MSS	Fucino	41	22	53.7	3	7.3	4	9.8	4	9.8	3
	207/29	MSS	Fucino	41	24	58.5	5	12.2	7	17.1	5	12.2	3
1981	206/29	MSS	Fucino	40	7	17.5	not available		7	17.5	6	15.0	3
	207/29	MSS	Fucino	40	5	12.5	not available		5	12.5	5	12.5	3
1982	206/29	MSS	Fucino	33	12	36.4	not available		6	18.2	4	12.1	3
	207/29	MSS	Fucino	33	12	36.4	not available		4	12.1	3	9.1	3
1983	192/29	MSS	Kiruna	26	10	38.5	1	3.9	1	3.9	1	3.9	3
		MSS	Fucino	26	20	76.9	4	15.4	6	23.1	1	3.9	3
1984	192/29	MSS	Fucino	42	24	57.1	2	4.8	4	9.5	3	7.1	3
		TM	Fucino	19	15	78.9	1	5.3	2	10.5	2	10.5	3
1985	192/29	MSS	Fucino	46	37	80.4	6	13	14	30.4	10	21.7	3
		TM	Fucino	23	19	82.6	2	8.7	5	21.7	4	17.4	3
EAST SESIA													
1980	209/28	MSS	Fucino	41	24	58,5	2	4.9	4	9.8	3	7.3	3
1981	209/28	MSS	Fucino	40	13	32.5	not available		6	15.0	5	12.5	3
1982	209/28	MSS	Fucino	33	13	39.4	not available		4	12.1	3	9.1	3
1983	194/28	MSS	Kiruna	26	10	38.5	none		none		none		
			Fucino	26	18	69.2	3	11.5	4	15.4	1	3.8	3
1984	194/28	MSS	Fucino	42	38	90.5	2	4.8	5	11.9	4	9.5	3
		TM	Fucino	19	17	89.5	1	5.3	3	21.1	2	10.5	3
1985	194/28	MSS	Fucino	46	42	91.3	7	15.2	13	28.3	6	13.0	3
		TM	Fucino	23	21	91.3	5	21.7	7	30.4	3	13.0	3

Moreover an other remarkable example of the importance of suitable LANDSAT image availability is given.
In the East Sesia irrigation district, the TM-image on 30 April, 1985 allowed the discrimination of main crops. The images of 3 July and 20 August, 1985 were then useful to detect the probable water shortage in corn, grass and rice fields.
On the other hand, in Grande Bonifica Ferrarese in 1985, the best temporal combination "image availability-differences in crop phenology" was achieved, only, for a few crops.

7. APPLICATIONS

7.1. Mapping agricultural areas

7.1.1. Declared versus actual crop cultivated area: a practical result

By applying the multi-temporal multi-index method, discrimination of crops in the considered irrigation districts achieved good results. Yearly crop maps are basic informations for the irrigation district board in order to forecast total crop water requirements.
Photo 1 respectively 2 (appendix 2) show crop maps of 1980 and 1985 of part of East Sesia irrigation district, where crop location did not changed so far. Remarkable it is, also, the detailed canal networks shown in photo 2 (TM-image), while in photo 1 (MSS-image) it is not visible. Moreover, a useful information for the irrigation district board extracted from the crop maps can be the control of the actual extension of the declared irrigated areas.
Photo 3 shows part of the territory of Grande Bonifica Ferrarese of a colour coded LANDSAT-TM image on 2 May 1985. Winter wheat, green at that time of the year, is indicated by red colour. Paddy rice fields are black, while gray-blue colour indicates bare soil and cultivated fields in which soil vegetation cover is lower than 25%. According to the interviews to the farmers done in September 1985, the black framed field in photo 3 should cultivated with winter wheat, however that field is cultivated with another crop (gray-blue colours).
Further support to such conclusion is given by a colour coded TM-image (photo 4) of the same area 4 months later (22 August 1985).
In photo 4 the so-called wheat field should appear in dark-blue-blue colour which denoted, at that time, the fields in which was previously grown wheat without a second crop. Nevertheless, the so-called wheat field is orange which denotes the presence of a spring-summer crop as it happened to the surrounding fields (soybeans cultivations).
Noting that the irrigation charges of the Grande Bonifica Ferrarese to the farmers are depending on the type of cultivated crops, we should remark that winter wheat belongs to the cathegory of non-irrigated crops while soybeans to the irrigated ones. So, that farm has cultivated in the year 1985 more hectares with irrigated crops than decla-

red to the irrigation district, with the consequence of paying less than due. In the Grande Bonifica Ferrarese irrigation district, probably, other mispayments on irrigation charges are occurring because the irrigation district itself does not check out the actual hectarage of irrigated crops taking for granted what the farmers declare. Consequently, in this case, a very useful application is the discrimination of crops by means of satellite images, in order to establish the hectarages of irrigated crops.

7.2. Assessment of water stress in cultivated crops growing in the study irrigation district during 1985

7.2.1. Water stress concept.

The occurrence of water deficit during the growth cycle of an agricultural crop reduces its biomass accumulation rate, which decrement is proportional to the intensity and duration of water stress. Several authors pointed out that a water stressed crop has:

1) a IR/Red reflectance ratio smaller than the one of a well watered crop (KAMAT et al., 1981; HATFIELD, 1981)
2) reflectances measured in the spectral interval 1.50-1.75 μm respectively between 2.00-2.35 μm are smaller than of the same crop when well watered (FERNS et al., 1983)

Moreover, temperature of a water stressed crop is higher than the temperature of well watered crop (JACKSON et al., 1981).
Crop temperature can be calculated from the radiation value emitted from the crop between the wavelengths 10.4-12.5 μm measured by band 6 of TM-sensor.

7.2.2. Water stress detection of crops cultivated in East Sesia and Grande Bonifica Ferrarese irrigation districts

The assessment of occurring crop water stress was done by means of the Landsat-TM images acquired in 1985 and by observing TVI, reflectances in bands 5 and 7 and temperature values.
Several ground control plots cultivated with grass and pasture in East Sesia were considered. Such values are shown in table 20, where, with high values of TVI (table 20, example a) temperature and reflectances in bands 5 and 7 are smaller than the values of temperature and reflectances corresponding with smaller TVI values occurred (table 20, example f).

Table 20. Measurements of TVI, reflectances in bands 5 and 7, and temperatures in °C calculated from several ground control areas cultivated with grass and pasture in East Sesia on the 3rd of July, 1985

TVI*100	BAND 5 (% reflectance)	BAND 6 (C°temperature)	BAND 7 (% reflectance)
a) 103.7	16.9	18.8	6.6
b) 102.5	17.6	18.5	6.9
c) 101.1	23.6	20.3	10.0
d) 99.9	21.7	20.5	9.3
e) 98.8	20.5	20.0	9.6
f) 93.1	28.0	22.0	17.1

Then we extracted from ground control plots pixel values of TVI, reflectances in band 5 and 7, temperature and the differences between such measurements and their average values (Table 21) was calculated.

Table 21. Average values of TVI, reflectances in bands 5 and 7 (R5,R7) and temperature (T °C) characterizing the ground control plots cultivated with grass and pasture in East Sesia in July and August, 1985.

	JULY	AUGUST
TVIX100	100	105.6
R5	20.3	16.9
R7	9.4	8.3
T C	19.8	21.9

Results are plotted on the graphs of Figs. 12,13,14 for July, where pixels having the temperature difference values (Tx-Tm)> +1 were the only ones taken into account.

Fig.12 shows that at temperature decreases, values of TVI increase and, vice-versa, at temperature increases TVI decreases.

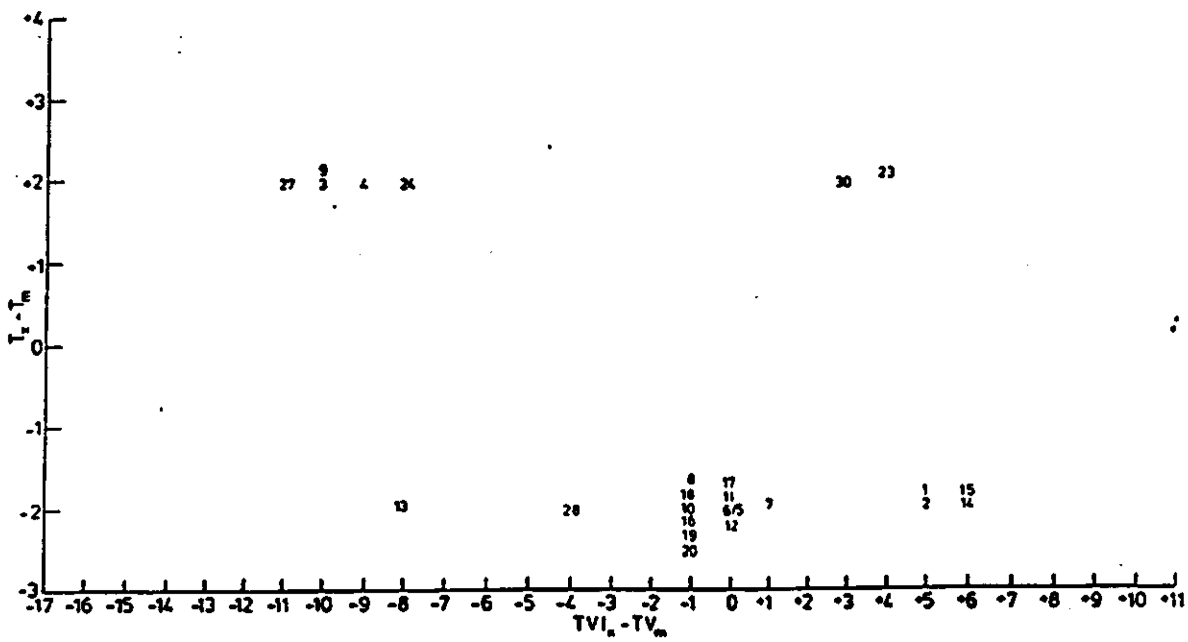

Fig. 12. TVI and temperature values minus the average values (table 21) characteristic of the ground plots cultivated with grass and pasture on July 1985 in East Sesia

TVIx, Tx TVI and temperature values of pixel units

TVIm, Tm average values of TVI and temperature characteristic of ground plots (table 21)

Figure 13 shows that the reflectance in band 5 decreases when TVI increases.

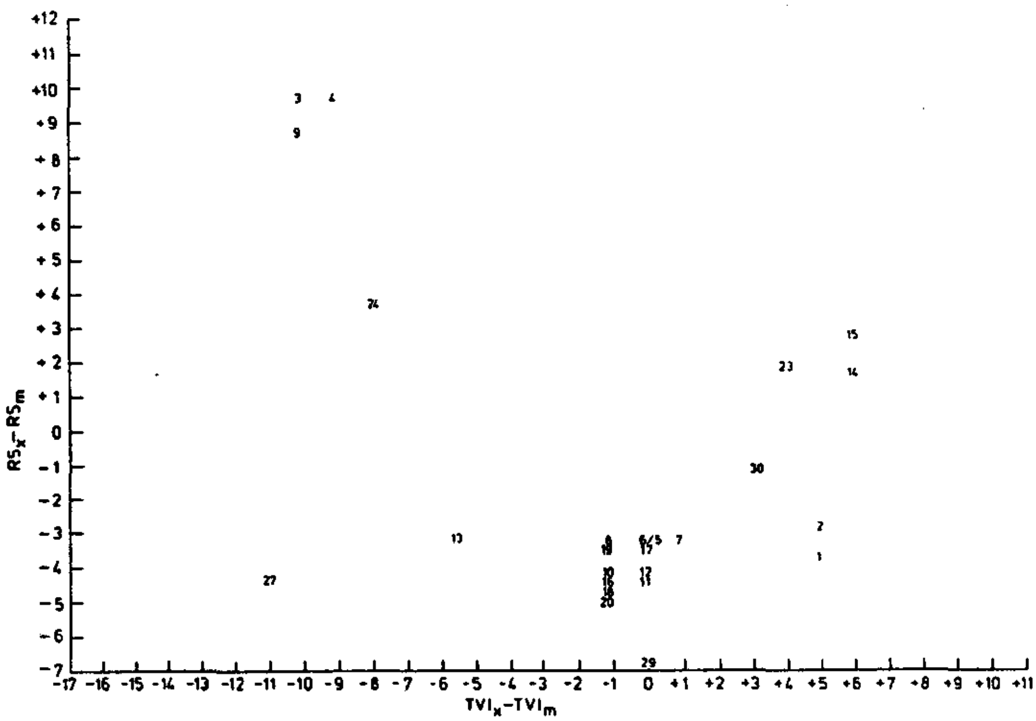

Fig. 13. TVI and reflectance values minus the average values (table 21) characteristic of the ground plots cultivated with grass and pasture on July, 1985 in East Sesia.
TVIx, R5x   TVI and reflectance band 5 values of pixel units
TVIm, R5m   average values of TVI and reflectance in band 5 characteristic of ground plots (table 21)

The same pattern of figure 13 is shown in figure 14, where reflectance values in band 5 are replaced by reflectance values in band 7.

Concerning the month of August, table 22 summaries the pattern of TVI values, reflectances in band 5 and 7, temperature, extracted from ground control plots, related to the average values of table 21. Table 22 shows, also, that water stress occurred to grass and pasture was only in pixel plot 16; therefore, water stress was quantitatively greater in July than in August 1985 in East Sesia.

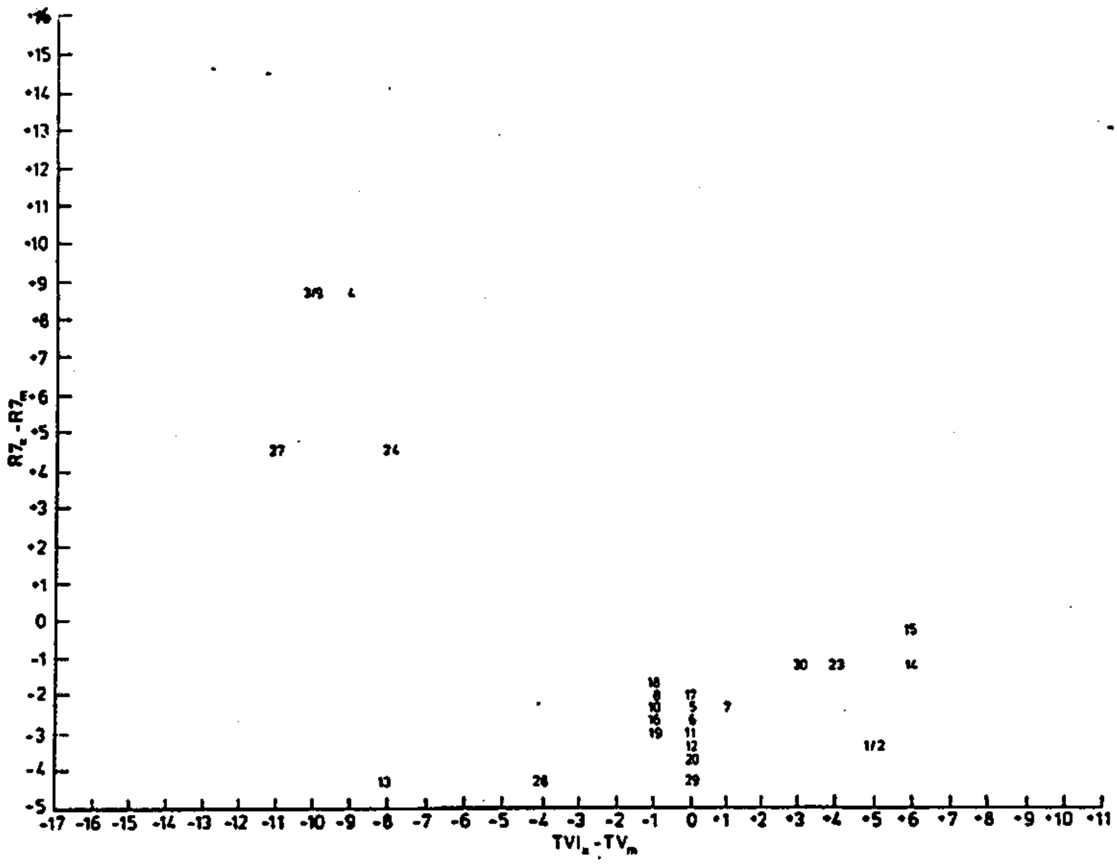

Fig. 14. TVI and reflectance values minus the average values (table 21) characteristic of the ground plots cultivated with grass and pasture on July,1985 in East Sesia.

TVIx, R7x TVI and reflectance band 7 values of pixel units

TVIm, R7m average values of TVI and reflectance band 7 characteristic of ground plots (Table 21)

By producing false colour satellite images water stress was localized in a very small part of the total area cultivated to grass and pasture even in the month of July.

In East Sesia irrigation district, water stress was detected only in small part of the territory cultivated with grass, while for rice and corn no water stress occurred in July and August.

In order to cross-check the results extracted by satellite images, the mathematical model called SWATRE was run for the whole year 1985 for East Sesia irrigation district.

Table 22. Pattern of TVI reflectance and temperature values, extracted from ground control plots, compared to the average values in Table 21.

\+ pixel values > than average values

\- pixel values < than average values

0 pixel values = average values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
TVI	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
B5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
B7	-	o	-	o	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Temperature	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-

SWATRE is a mathematical model which simulates the soil water balance (BELMANS et al., 1983).

SWATRE, simulating the water balance in different parts of the East Sesia territory, did not detect any water shortage for rice and corn in July and August 1985.

Then, the results of SWATRE model confirm and support the validity of the method which was used with the satellite images.

The same method was also applied in Grande Bonifica Ferrarese. Crops as soybeans I harvest and corn were considered, being these crops rather sensitive to any water shortage.

The only TM-image suitable for water stress detection was that of 22 August, 1985. The values of TVI, reflectances in band 5 respectively 7 and temperature did not show any significative and correlated deviations.

Such results bring to the conclusion that on 22 August 1985 soybeans I harvest and corn did not suffer of any lack of water in the Grande Bonifica Ferrarese irrigation district.

Nevertheless during the interviews conducted in September 1985 in both the irrigation districts farmer complaints rose, mainly, upon the water shortage caused by a very dry and exceptional hot summer.

On the other side, the board of the Grande Bonifica Ferrarese irrigation district rose complaints on the huge quantity of water that had to be pumped out from the district territory (which is in part under sea level) during the 1985 irrigation season, in order to prevent waterlogging.

So the results of satellite data analysis have been confirmed by the water management applied in 1985.

7.3. Water depth detection in paddy rice fields

7.3.1. Water levels in paddy rice field located in East Sesia and Grande Bonifica Ferrararese irrigation districts

Rice is cultivated in both the study areas but in East Sesia such crop is the main one. The possibility of the assessment of water level in the rice basins by means of satellite images can be useful to check the occurrence of rice field flooding and possibly the quantity of water delivered to the rice farms.

In the Grande Bonifica Ferrarese, rice is mainly cultivated on peat soil characterized by high organic matter content and by dark colour. Such type of soil, being a negative constraint for the other crops there cultivated, is only used for rice cultivation.

Both the water content and the percentage of organic matter influence very much soil reflectance, showing low reflectance values when soils are wet and have high content of organic matter.

In the East Sesia rice is cultivated on soils of different textures and different organic matter contents. Then, the soil reflectance variability due to different water levels in paddy rice fields is easier to be analysed, at first, in the Grande Bonifica Ferrarese territory where only one type of soil is suitable to rice cultivation.

By the time of the first TM-image acquisition (2 May,1985) only a part of rice fields were flooded in the Grande Bonifica Ferrarese, as it was confirmed by the data collected in the ground control plots.

TVI and reflectances values of band 5 respectively 7 of paddy rice control plots having the same type of soils and different water level depths in the basins, have been obtained with the 2 May TM-image. It appeared that only the 2/5 of rice cultivated area was at that time flooded. Figs. 15-16-17 show the measurements correlating the values of TVI and reflectances in band 5 respectively 7 at different water depths in basin rice fields. At low water level (5 cm) values of TVI and reflectances in bands 5 and 7 are higher where higher water level occurs (15 cm).

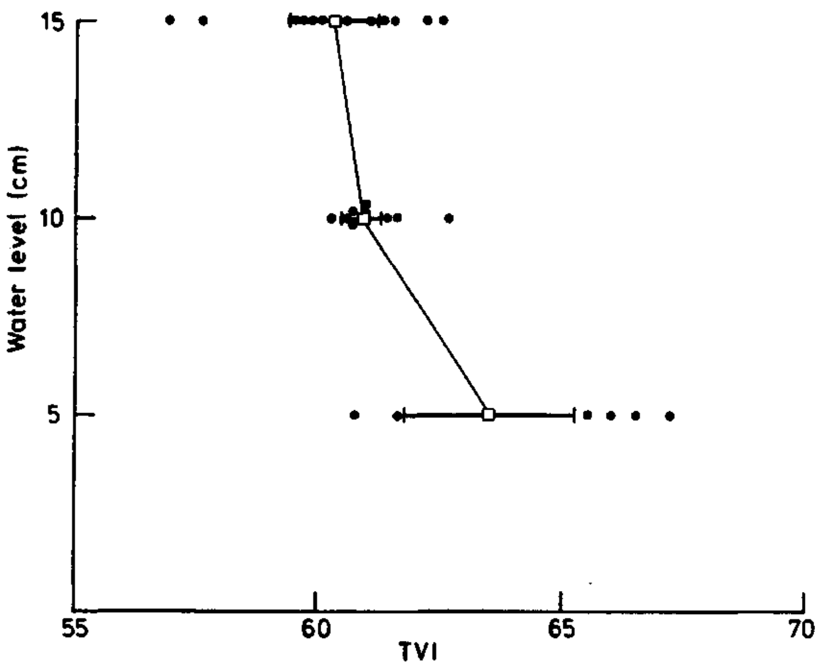

Fig. 15. TVI values extracted from TM-image 2 May, 1985 for paddy rice fields versus water level depth in rice basins in Grande Bonifica Ferrarese irrigation district.

- ● extracted value
- □ average value
- ├──┤ standard deviation

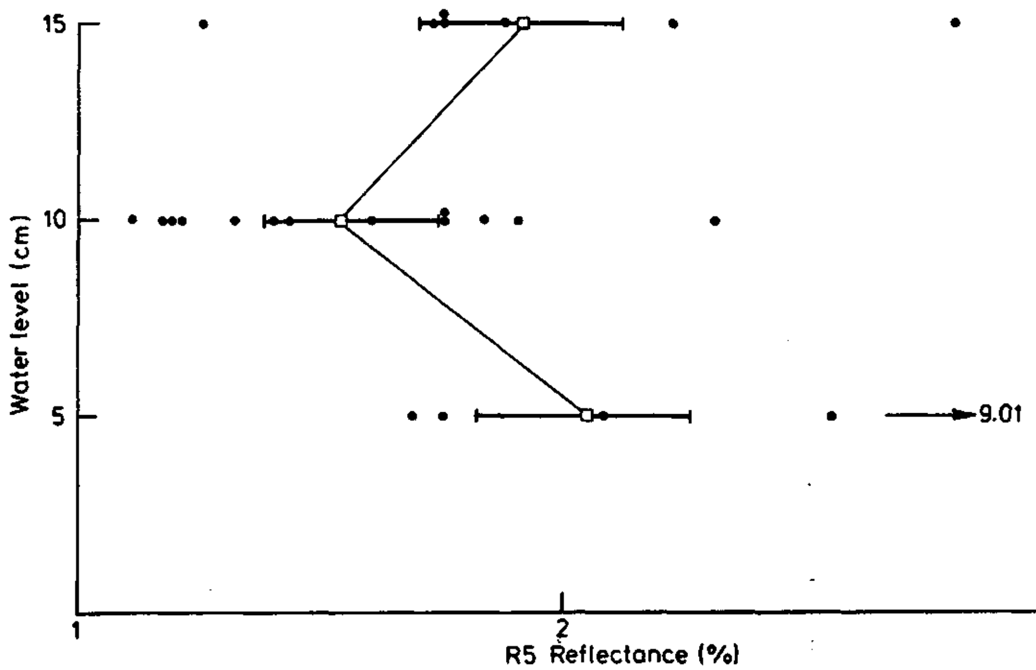

Fig. 16. Reflectance (TM band 5) versus water level depth in rice basins; Grande Bonifica Ferrarese irrigation district; 2 May 1985.

• extracted value □ average value ⊢⊣ standard deviation

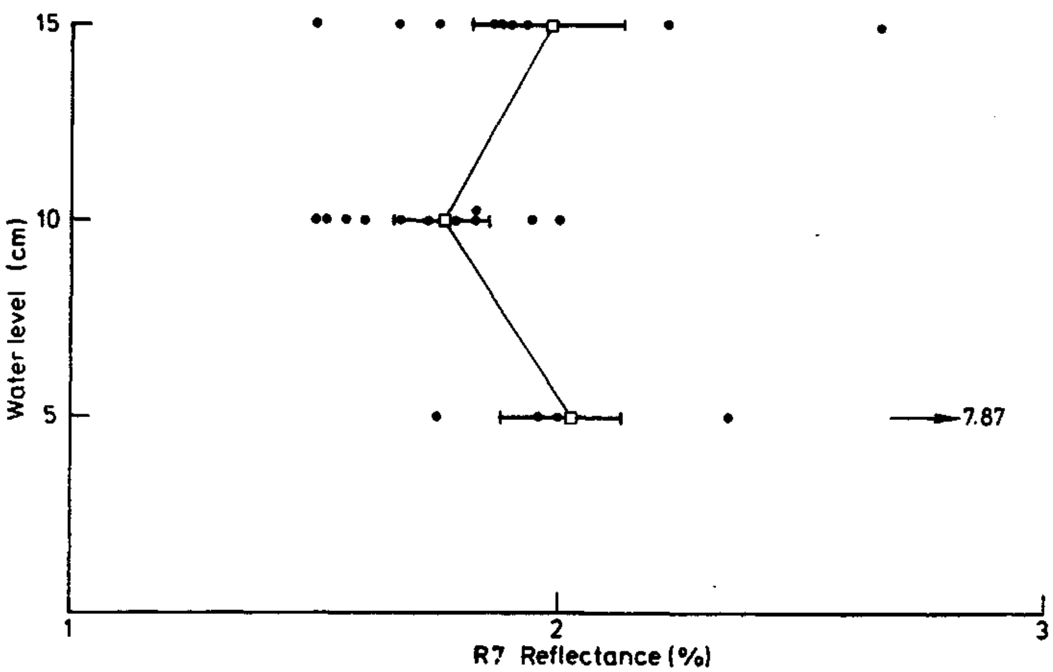

Fig. 17. Reflectance (TM band 7) versus water level depth in rice basins; Grande Bonifica Ferrarese irrigation district; 2 May 1985.

• extracted value □ average value ⊢⊣ standard deviation

Photo 5 in appendix 2 shows part of the Grande Bonifica Ferrarese irrigation district (false colour TM-image; 2 May,1985).

Part of the rice fields, flooded at that time, was classified according to the TVI characteristic interval "method a" (55-67) calculated in May. Water levels $\geqslant$10 cm which corresponds to the interval of TVI values between 55 and 60 (Fig.15), while the interval of TVI values between 61 and 65 corresponds to water levels$\leqslant$5 cm in the rice fields.

In order to analyse the water distribution in the rice basins by means of TVI in East Sesia ,we will use the same correlation observed between TVI measurements and water levels in rice basins of Grande Bonifica Ferrarese. Photo 6 in appendix 2 shows a false colour TM-image of 30 April,1985, where rice fields are discriminated by means of TVI within the interval of values between 50 and 67(see table 17). The rice fields having a TVI characteristic interval between 50 and 55 were evidenced by blue colour, while by green colour between 56 and 60 and by red colour between 61 and 67.

Subsequently, according to the correlation between TVI measurements at different water depths in rice basins found in Grande Bonifica Ferrarese, photo 6 shows that mainly in the west part of the East Sesia territory 5 cm or less of water (red colour) are applied in the rice fields, while in the east part a bigger amount of water is applied (10 cm and more evidenciated by green and blue colours in photo 6). Nevertheless, the collected informations on water dephts at seeding stage of rice basins shown that, in the rice control plots of East Sesia located in the west part of photo 6, water depth more than 10 cm was applied. Then the correlation "TVI values-different water levels" observed in Grande Bonifica Ferrarese rice fields does not have any correspondence with the TVI measurements observed in East Sesia rice fields. However, the presence of different type of soils in East Sesia can explain such unespected TVI pattern.

Infact, analysing the soil map of a part of East Sesia irrigation district (Fig. 18), two main soil associations are there present according to the FAO-UNESCO classification (FAO-UNESCO, 1974):

1) Eutric Histosols, located in the east part of the district
2) Dystric Cambisols, located in the west part of the district.

A brief description of such soils is given.
An Eutric Histosols soil is characterized by an H horizon where accumulation of organic matter can reach 30%, presence of dark peat, slow drainage, presence of water table at 30-60 cm from the surface, very fertile.

A Dystric Cambisols is a deep soil having medium drainage, A horizon is characterized by low organic matter content and light colour, texture of B horizon is mainly composed by fine sandy loam.

Higher TVI values are recorded for a lighter texture soil (sandy soil), while a heavy dark soil (podzol) shows low TVI values.

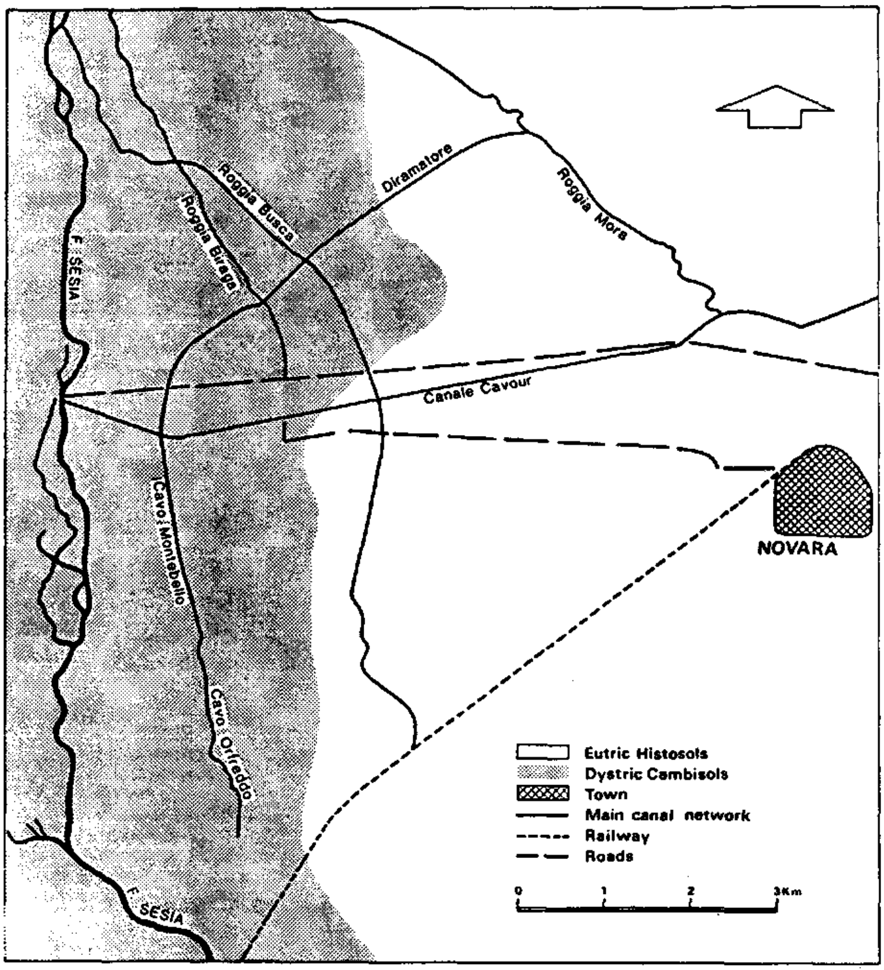

Fig. 18. Sketch of part of East Sesia irrigation district where river, city, main irrigation networks, roads and soil types have been evidenciated

Subsequently, according to Fig.18, in the west part (Distric Cambisols) of the irrigation district TVI values of flooded rice fields at same water level should be higher than the same values extracted from the east part (Eutric Histosols) of the territory.

Indeed, looking at photo 6 the highest percentage of TVI values between 56 and 67 is recorded mainly in the light soils (Distric Cambisols). Moreover, the Grande Bonifica Ferrarese soil on which rice is cultivated is very similar to the Eutric Histosols of East Sesia. Such similarity shows that the relation derived for Grande Bonifica Ferrarese has been confirmed by water depth data in Eutric Histosols in East Sesia, as conclusion supported by the farmers which have given the average height of water applied in the rice basins in the year 1985.

Photo 6 shows, also, that in the Eutric Histosols soil paddy rice fields were flooded with different amount of water variating between 25 and 5 cm. The blue colour of photo 6 is attributed to TVI values between 50 and 55, which are indicating a water level of 20-25 cm in the paddy rice fields.

Nevertheless, an example of fraud, as it was shown also in paragraph 7.1.1, is given from the paddy rice fields framed by a white circle in photo 6. Even though the rice field owner declared that a water level of 5 cm was there applied at seeding stage, giving the classification of different water levels in rice basins by means of TVI, photo 6 shows that farm was, instead, applying from 10 till 25 cm of water. Considering that water charges for rice fields are related to the declared water quantity supplied in the fields, such farm has paid 1/3-1/4 less than the right amount which should have been paid during the seeding time in 1985.

8. CONCLUSIONS

From the beginning of 1984 ESA/EARTHNET has promoted the operational use of LANDSAT-images through pilot projects. Such pilot projects are feasibility studies of practical applications of satellite data. On the other hand, the European Communities, in the framework of the "Collaborative program on rural land use for less-favoured areas" coordinated by the Joint Research Center (Ispra establishment) has promoted the use of LANDSAT-images in land use evaluation, particularly:

1) to facilitate collection of agricultural statistical data;
2) to improve management of land resources in less well developed European areas;
3) in the identification and monitoring the effects of management decisions;
4) to monitor environmental pollution.

The potential for operational use of LANDSAT-images to map land cover in Europe is currently being investigated in the framework of program "Corine" of the EEC.

The project described in this report was supported by EARTHNET as a pilot project and its purpose was to develop an operational method able to determine quality, quantity and type of crops and to assess probable water stress by means of LANDSAT-images in two districts located in the Po valley (East Sesia and Grande Bonifica Ferrarese).

Crop identification and classification performed by the multitemporal multi-temporal method with LANDSAT MSS respectively TM images, have shown how useful accurate reference data are.

The procedure, shows that it was essential to have a rather consistent amount of ground truth plots and a detailed crop calendar applying to the current year in order to interpret properly the satellite images. Moreover, the application of different vegetation indices in a combined manner enhances the opportunities for classification of crops which present similar growth cycle. The achieved crop discrimination by the LANDSAT images gives the possibility to produce crop maps of the study areas, useful for statistical studies. On the other hand, location of the cropped area can be usefully utilized for estimation of the actual cultivated area when crop cultivation is subsidized.

If the final objective of the application is a reliable crop classification, images from LANDSAT MSS or TM can be used likewise. Using TM images is only more convenient if the average size of crop fields in the area object of study is 10 ha or less (higher resolution in TM than in MSS : 30 m versus 80 m).

The subject "detection of water stress" deserves a special attention. The used method by means of TM-images has shown remarkable results, to point out occurred water stress in the main cultivated crops of East Sesia and in two cultivated crops of Grande Bonifica Ferrarese. These results, obtained by satellite images, were checked via a mathematical model (SWATRE), by simulating the soil water balance for the whole 1985 in the two study districts.

The model SWATRE confirmed the same results obtained by the satellite images : no water stress caused by water shortage has occurred in the considered months for the main cultivated crops. This type of research can also help to estimate how much water, delivered in the main district network, is not utilized for irrigation.

Furthermore, the quantity of water delivered during the seeding stage of rice fields was detected by means of TVI for different soil types. Such results can assess the uniformity of water application by the water management board.

Moreover, the irrigation water set free for other uses by a better targeted allocation would further enhance the scope of irrigated crop monitoring by LANDSAT.

ACKNOWLEDGEMENTS

Grateful thanks is given to Dr. Massimo Menenti both for his valuable scientific and technical support and for dedicating so much of his time and experience to build up this research and to improve its development.

The research described in this report has been sponsored by the European Commission, in the form of research fellowship to the author, who gratefully acknowledges this support.

East Sesia and Grande Bonifica Ferrarese irrigation districts deserve a special mention for sponsoring and helping the author in the field campaign in September 1985.

REFERENCES

AGAZZI, A. and G. FRANZETTI, 1975. Effects of rice biomass and yield on reflectance in the LANDSAT channels. Agreste report 15, JRC-ISPRA Establishment, 51 pp.

ANDERSON, J.W., 1986. Remote sensing finds down-to-earth applications. Commercial Space

AZZALI, S., 1985a. A multi-index multi-temporal approach to map crops in the early growing season. An application to two Italian irrigation districts: East Sesia and Grande Bonifica Ferrarese. ICW Nota 1611, Wageningen, 39 pp.

AZZALI, S., 1985b. Greenness and brightness formulae applicable to East Sesia and Grande Bonifica Ferrarese. ICW Nota 1673. Wageningen. 32 pp.

AZZALI, S. 1986. Matching the analysis of Landsat data to users's requirements. ICW Nota 1711. Wageningen. 15 pp.

BADHWAR, G.D., 1984. Use of Landsat-derived profile features for spring small-grains classification. International Journal of Remote Sensing. Vol. 5., no. 51, p. 783-797.

BELMANS, C., J.G. WESSELING and R.A. FEDDES, 1983. Simulation model of the water balance of a cropped soil: SWATRE. Journal of Hydrology, 63, p. 271-286.

CLERMONT, L. and M. MENENTI, 1984. Agricultural water use in the Po basin (Italy). Remote sensing studies. ICW Note 1582, Wageningen, The Netherlands.

COLWELL, R.N. and C.M. HAY, 1979. Development of AI procedures for dealing with the effects of episodal events on crop temporal spectral response and development of AI guidelines for corn and soybeans labeling. Annual progress report for NASA contract NAS 9-14565, Agristars.

CURRAN, P.J., 1981. Multispectral remote sensing for estimating biomass and productivity: "Plants and the daylight spectrum" edited by H. Smith. Academic Press (65-99).

DOORENBOS, J. and W.O. PRUITT, 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24. FAO, Rome. 156 pp.

DOORENBOS, J. and A.H. KASSAM, 1979. Yield response to water. FAO Drainage Paper 33. FAO, Rome. 193 pp.

FAO-UNESCO, 1974. Soil map of the world 1 : 5.000.000. Volume I. Legend. Edited by Unesco - Paris 1974. pp.59.

FERNS, D.C., S.J. ZARA and J. BARBER, 1983. Application of high resolution spectroradiometry to vegetation. Field Radiometry Proceedings of Remote Sensing Society and the Royal Society of Chemistry, 2 February 1983. 82 pp.

HALL, F.G. and R.B. MacDONALD, 1983. A survey of automated remote sensing for agriculture. Proceedings: 1983 international geoscience and remote sensing symposium (IGARSS 1983). Vol. II, p. FA-5 1.1-1.12.

HALL, K., 1984. Studies on the qualitative influence of various biological and physical parameters on Landsat MSS data. Lunds Universitets Naturgeografiska Institution. Rapporter och Notiser 59, Lund, Sweden, 47 pp.

HATFIELD, J.L., 1981. Irrigation scheduling with thermal infrared and spectral remote sensing inputs. Irrigation scheduling for water and energy conservation in the 80's. Proceedings of ASAE-ISC. December, p. 10-17.

HATFIELD, J.L., 1983. Evapotranspiration obtained from remote sensing methods in "Advances in Irrigation". Vol. 2 by D. Hillel, Academic Press.

INFORMATORE AGRARIO, 1980-1981. Rivista settimanale di Agricoltura . Ed. Verona.

ISTITUTO CENTRALE DI STATISTICA (ISTAT), 1982. Annuario di statistica agraria. Vol. XXVIII, edizione 1981, Roma.

IPLA, 1979. Isituto Nazionale per Piante da Legno "G. Piccarolo", Torino. Regione Piemonte. Carta della capacità d'uso dei suoli e delle loro limitazioni. Regione Piemonte. Assessorato alla pianificazione del territorio e dei parchi naturali.

JACKSON, R.D., S.B. IDSO, R.J. REGINATO and P.J. PINTER, 1981. Canopy temperature as a crop water stress indicator. Water resources research. Vol. 17, no. 4, p. 1133-1138.

JACKSON, R.D., 1982. Canopy temperature and crop water stress in: Advances in irrigation. Vol. 1., p. 43-80. Edited by Daniel Hillel, Academic Press.

JACKSON, R.D., P.N. SLATER and P.J. PINTER, 1983. Discrimination of growth and water stress in wheat by various vegetation indices through clear and turbid atmospheres. Remote sensing of environment 13, p.187-208.

JOHNSON, W.R. 1981. A temporal/spectral analysis of small grain crops and confusion crops. Lockheed Engineering and Management Service Company for NASA in AGRISTARS.

KAMAT, D.S., A.K.S. GOPALAN, AJAI, M.N. SHASHIKUMAR, S.K. SINHA, G.S. CHATURVEDI and A.K. SINGH, 1985. Assessment of water-stress effects on crops. International Journal of remote sensing. Vol. 6, no. 3-4, p. 577-589.

KAUTH, R.J. and G.S. THOMAS, 1976. The tasselled cap - a graphic description of the spectral-: temporal development of agricultural crops as seen by Landsat. Proc. Symp. Machine proc. Rem. Sensed Data, LARS, Vol. 4B, p. 41-50.

L.A.C.I.E., 1978. Crop spectra from Lacie field measurements N79-18401. (Purdue University), 192 pp.

L.A.R.S., 1968. Remote multispectral sensing in agriculture. Research Bulletin 844, Purdue University, Lafayette, Indiana, USA, 175 pp.

MARTINI, S. and M.R. SCIARRETTA, 1977. Analisi del bilancio di radiazione (400-1350 nm) di un vigneto. Studi di ecologia agraria. Ministero dell'Agricultura e delle Foreste. Ufficio centrale di Ecologia agraria e difesa delle piante coltivate dalle avversitá meteoriche, Roma, Italy. 17 pp.

MENENTI, M., S. AZZALI, S. LEGUIZAMON et D.A. COLLADO, 1986. Multitemporal analysis of LANDSAT Multispectral Scanner (MSS) and Thematic Mapper (TM) data to map crops in the Po valley (Italy) and in Mendoza (Argentina). Proceedings of the 7th International Symposium on Remote Sensing for Resource Development and Environmental Management. Enschede, 25-29 August 1986. 1, p. 293-299.

MILLER, G.E., 1981. (Lockheed Engineering and Management). A look at the commonly used Landsat vegetation indices. N82-2165 7, 37 pp.

NIER-CER, 1984. Usi agricoli dell'acqua nel bacino del Po. Chapter 5, p. 1-222, Bologna, Italy.

PINTER Jr., P.J., 1982. Remote sensing of microclimatic stress. Biometeorology in Integrated Pest Management, p. 101-145, Academic Press.

PINTER Jr., P.J., R.D. JACKSON, S.B. IDSO, and R.J. REGINATO, 1981. Multidate spectral reflectance as predictors of yield in water stressed wheat and barley. International Journal Remote Sensing. Vol. 2, no.1, p. 43-48.

ROUSE Jr., J.W., R.H. HASS, J.A. SCHELL and D.W. DEERING, 1973. Monitoring vegetation systems in the great plains with ERTS. Third ERTS symposium, NASA SP-351. December 10-14, I, p. 309-317.

SEELEY, M.W., D.L. RUSCHY and D.R. LINDEN, 1983. Variation in thematic mapper spectra of soil related to tillage and crop residue management; initial evaluation. International Geoscience and Remote Sensing Symposium (IGARSS '83), 31 Aug.-2 Sept. 1983, San Francisco, p. 2.1-2.5.

STEVEN, M.D., P.V. BISCOE and K.W. JAGGARD, 1983. Estimation of sugar beet productivity from reflection in the red and infrared spectral bands. International Journal of Remote Sensing. Vol. 4, no.2, p. 325-334.

UNGAR, S.G., W. COLLINS, J. COIMER et al., 1977. Atlas of selected crop spectra. Imperial Valley, California. NASA/GSEC N78-31499, Greenbelt, MD. 195 pp.

WOOD, B.L. and L.H. BECK, 1982. A geographic information system for Colusa county, California. 1982 Machine processing of remotely sensed data symposium, p. 394-401.

LIST OF CODES

Codes of the crop-data-sets considered in Tables 8, 9 and 10 (after AZZALI, 1985b)

Code	Crop Data Set	Reference
A_1	winter wheat	Ungar et al. (1977)
A_2	winter wheat	Johnson (1981)
A_3	winter wheat	Clermont and Menenti (1984)
A_4	winter wheat well watered	Pinter et al. (1981)
A_5	winter wheat stressed	Pinter et al. (1981)
B_1	rice	Clermont and Menenti (1984)
B_2	rice	Wood and Beck (1982)
B_3	rice	Agazzi and Franzetti (1975)
C_1	pasture	Johnson (1981)
C_2	pasture	Badhwar (1984)
C_3	pasture	Wood and Beck (1982)
C_4	pasture mixed	Wood and Beck (1982)
D_1	haygrass	Johnson (1981)
D_2	haygrass	Badhwar (1984)
D_3	haygrass	Clermont and Menenti (1984)
E_1	alfalfa	Johnson (1981)
E_2	alfalfa	Wood and Beck (1982)
E_3	alfalfa	Tucker et al. (1980)
E_4	alfalfa	Ungar et al. (1977)
	(The values into parenthesis correspond to the stage of the alfalfa cuttings)	
F_1	summer horticultural crops	Ungar et al. (1977)
G_1	sugar beet	Ungar et al. (1977)
G_2	sugar beet	Johnson (1981)
G_3	sugar beet	Steven et al. (1983)
H_1	idle fallow	Johnson (1981)
I_1	corn	L.A.R.S. (1968)
I_2	corn	Ungar et al. (1977)
I_3	corn	Tucker et al. (1979)
I_4	corn	Johnson (1981)
I_5	corn	Clermont and Menenti (1984)

L_1	trees	Johnson (1981)
L_2	orchard	Wood and Beck (1982)
M_1	stubble (corn residue)	Seeley et al. (1983)
N_1	vineyard var. Sangiovese	Martini and Sciarretta (1977)

LANDSAT MSS AND TM PRODUCTS

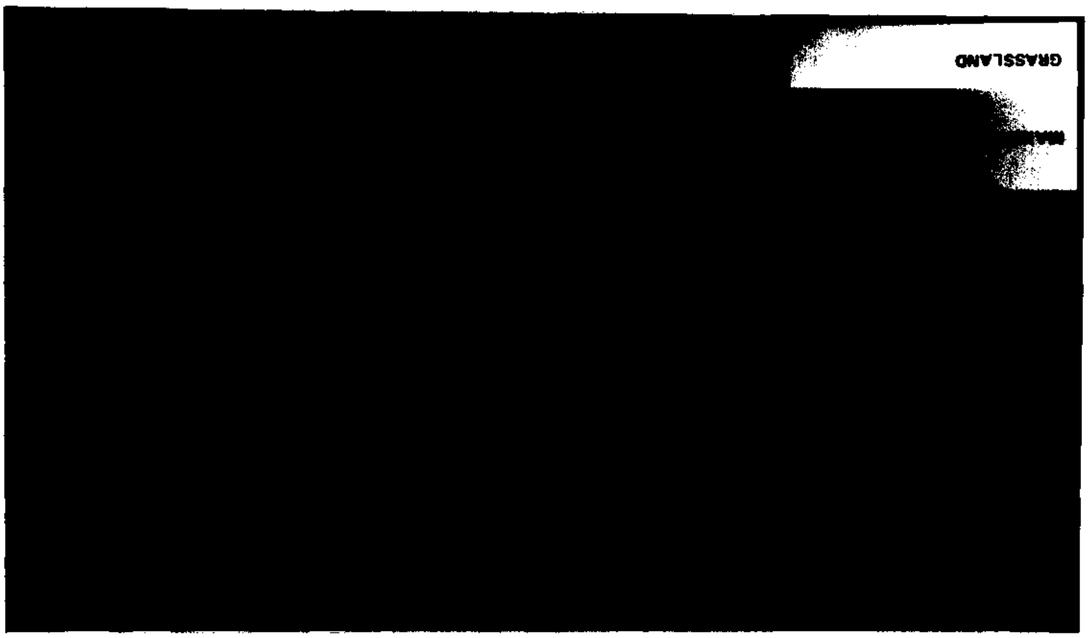

Photo 1 - Colour coded TVI image of East Sesia irrigation district where crops are classified according to the legend ; April 4, August 8 and September 9, 1980; LANDSAT-MSS data.

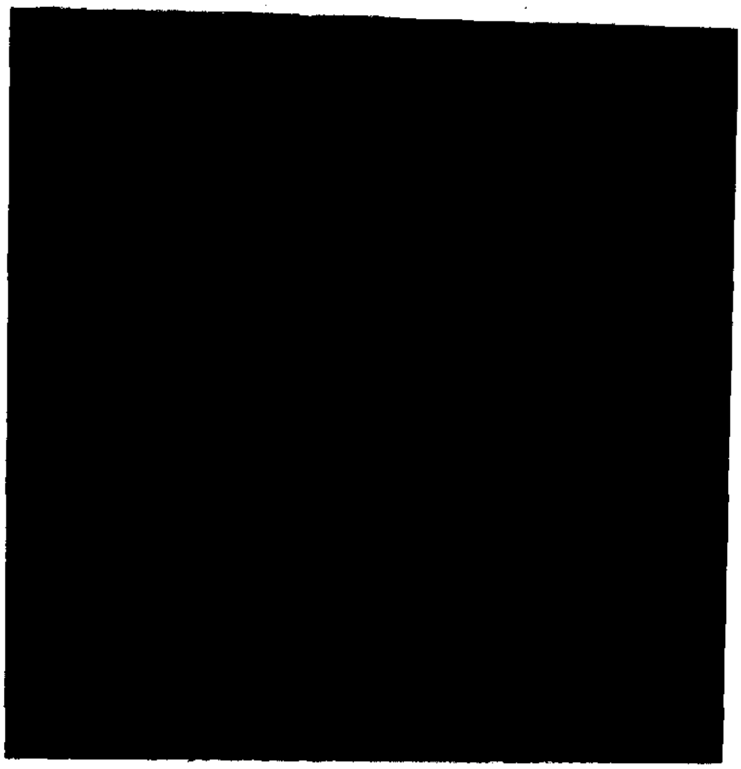

Photo 2 - Colour coded TVI image where rice is shown in blue, corn in green, pasture and haygrass in red, natural vegetation and poplar trees in yellow; April 30, 1985; LANDSAT-TM data, East Sesia irrigation district.

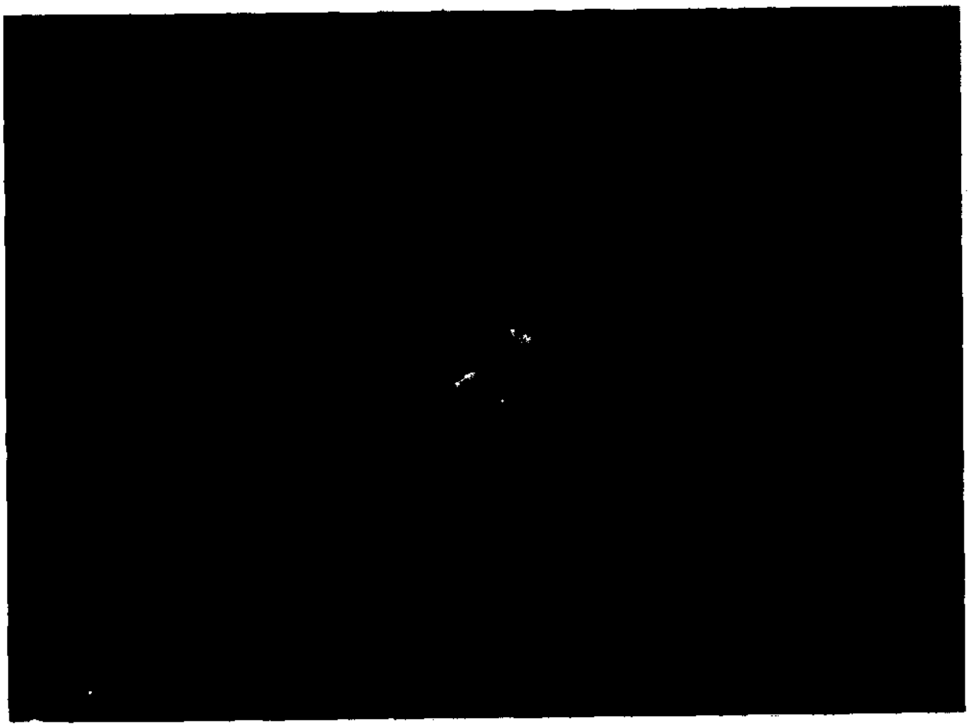

Photo 3 - Colour coded (bands 4/3/2) TM-image of Grande Bonifica Ferrarese, where full green winter wheat is red, paddy rice fields are black and emerging vegetation plus bare soil is gray-blue; May 2, 1985, LANDSAT-TM data.

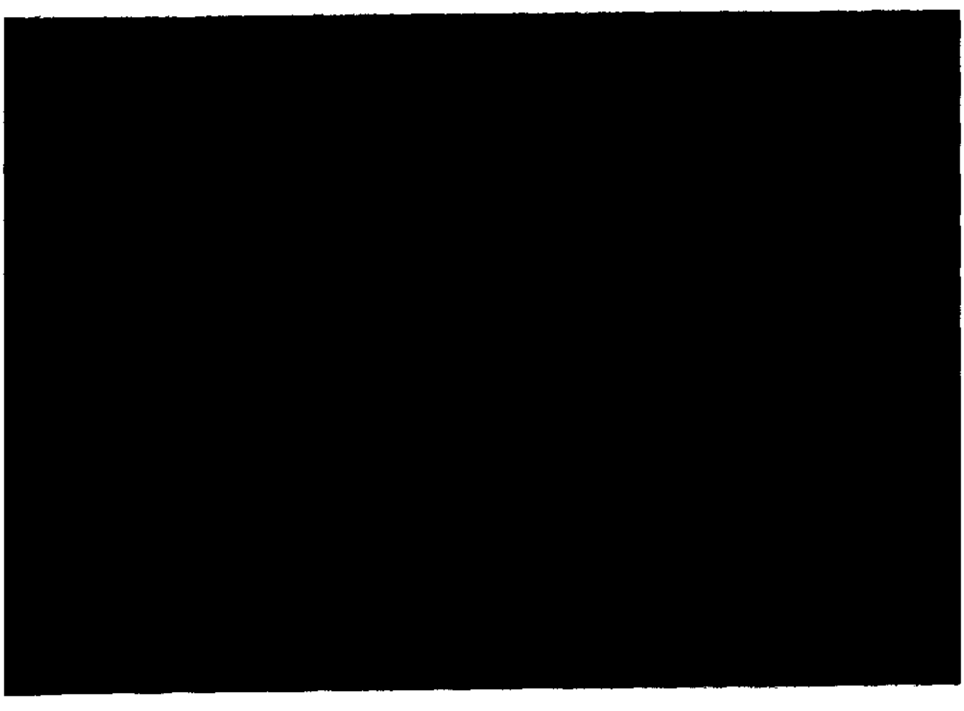

Photo 4 - Colour coded (bands 4/3/2) TM-image of Grande Bonifica Ferrarese, where full green corn, soybeans, rice, sugar beet are red-orange, stubble plus bare soil are dark blue to blue; August 22, 1985, LANDSAT-TM data.

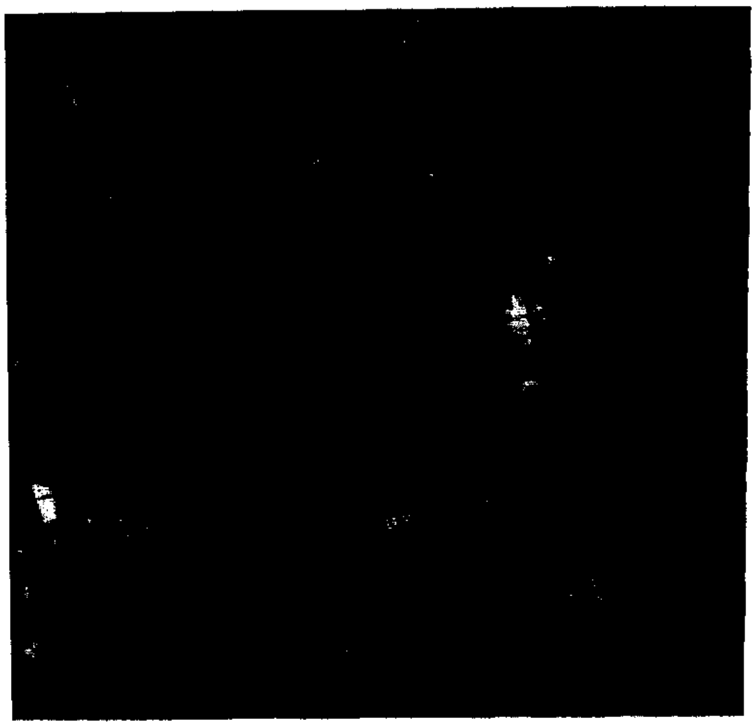

Photo 5 - False colour LANDSAT-TM image of TVI of Grande Bonifica Ferrarese on May, 1985 where paddy rice fields are classified by the TVI interval values 55-60 (green colour) when 10 cm or more are applied to the field, by the interval values 61-65 (red colour) when 5 cm. or less are applied to the field, by the interval values 66-67 (blue colour) when flooding process in rice basins.

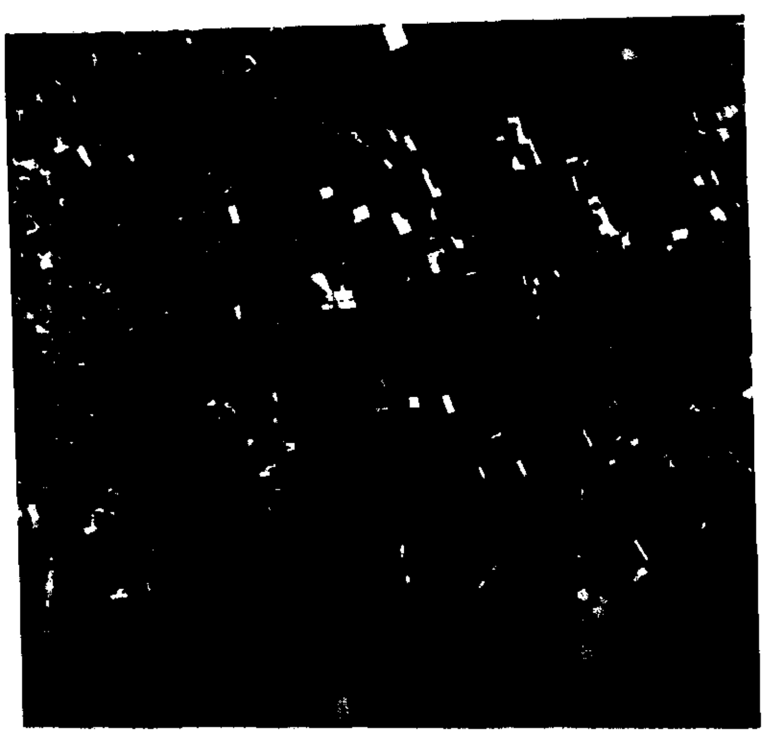

Photo 6 - False colour LANDSAT-TM image of TVI of East Sesia on 30 April 1985, where paddy rice fields are classified by TVI interval values 50-55 with blue colour, by TVI interval values 56-60 with green colour, by TVI interval values 61-67 (red colour). By a white circle, a rice farm is framed.