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GREENNESS AND BRIGHTNESS FORMULAE APPLICABLE TO EAST SESIA AND GRANDE BONIFICA FERRARESE

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C O N T E N T S

1. COMPUTING THE NEW SOIL LINE FOR THE EAST SESIA AND GRANDE BONIFICA FERRARESE

1.1. Introduction

One of the main weak points in the research presented by AZZALI (1985) was the use of the two vegetation indices formulae, respectively brightness and greenness, derived for a particular area in USA (JACKSON et al., 1983). Considering the fact that the coefficients of the brightness and greenness formulae are strictly correlated with the type of soils (KAUTH and THOMAS, 1976), these coefficients should have been calculated for the new study areas East Sesia and Grande Bonifica Ferrarese.

The procedure to compute the new coefficients of the brightness and greenness formulae can be divided in different steps.

1.2. Main soil associations in the two study areas

As it was pointed out by AZZALI (1985), the most important soil association found in the East Sesia irrigation district are two: typic hapludalfs chromic luvisols and typic hapludalfs gleyc luvisols (IPLA, Torino, 1979). In the irrigation district Grande Bonifica Ferrarese the main soil associations are two: the alluvial soils group and the organic idromorphic soils group. The latter soil association characterizes mainly the area of Grande Bonifica Ferrarese as shown by CASALICCHIO et al. (1974).

1.3. Bare soil and fully vegetation covered plots in the images

Considering that bare soil shows up in the early growing season (March, April, May), we selected the MSS-images of April respectively May 1980 for East Sesia respectively Grande Bonifica Ferrarese. For each irrigation district a standard LANDSAT 2-MSS colour composite product (MSS7 = red, MSS5 = green, MSS4 = blue) was prepared in order to evidence bare soil, which is characterized by light blue-grey colour. On these MSS-products bare soil areas have been chosen with regard to the soil associations mentioned in Section 1.2. For each selected and uniform bare soil plot the values of reflectances in bands 4, 5, 6 and 7 were collected. As test on the light brue-grey colour areas (bare soil) shown on the colour composite MSS-products, we checked the values of the ratio of reflectance in band 7 to the reflectance in band 5 which have been found in the range between 1.05 and 1.5. Such range represents the characteristic interval for bare soil (HUETE et al., 1984).

On the same standard MSS colour composite used for the detection of bare soil plots, we also selected the fully vegetation covered plots, which are characterized by red colour.

Furthermore, we checked if in the red colour areas of the standard MSS-products the values of the ratio of reflectance in band 7 to the reflectance in band 5 were between the values of 3 and 5, which represent the interval of reflectances for a healthy, green and fully covering canopy (UNGAR et al., 1977). Such procedure had successful results on the standard MSS colour composite product of Grande Bonifica Ferrarese in which several samples of full green vegetation areas were pointed out.

1.4. Calculation of the new coefficients of greenness and brightness formulae

Having collected for several bare soil and green plots the mean values of reflectances in MSS bands 4, 5, 6 and 7, we plotted on x-y axis the values of reflectances, respectively for bands 5 and 7, for each bare soil and green stuff sample picked up in the two irrigation districts. As Fig. 1 shows, the bare soil points are lying on a line, the so-called soil line, while the green stuff points cluster together in the so-called green stuff region.

Selecting two bare soil samples and a green stuff plot, we used their values of reflectance in the four bands of LANDSAT 2 - MSS to calculate the new coefficients for brightness and greenness formulae by means of the Gram-Schmit relation (KAPLAN, 1984).

Then, the new coefficients for the brightness and greenness formulae applicable to both the irrigation districts (East Sesia and Grande Bonifica Ferrarese) are:

$$\text{brightness} = 0.068\ \text{MSS4} + 0.124\ \text{MSS5} + 0.146\ \text{MSS6} + 0.29\ \text{MSS7} \qquad (1)$$

$$\text{greenness} = -0.085\ \text{MSS4} - 0.159\ \text{MSS5} + 0.058\ \text{MSS6} + 0.327\ \text{MSS7} \qquad (2)$$

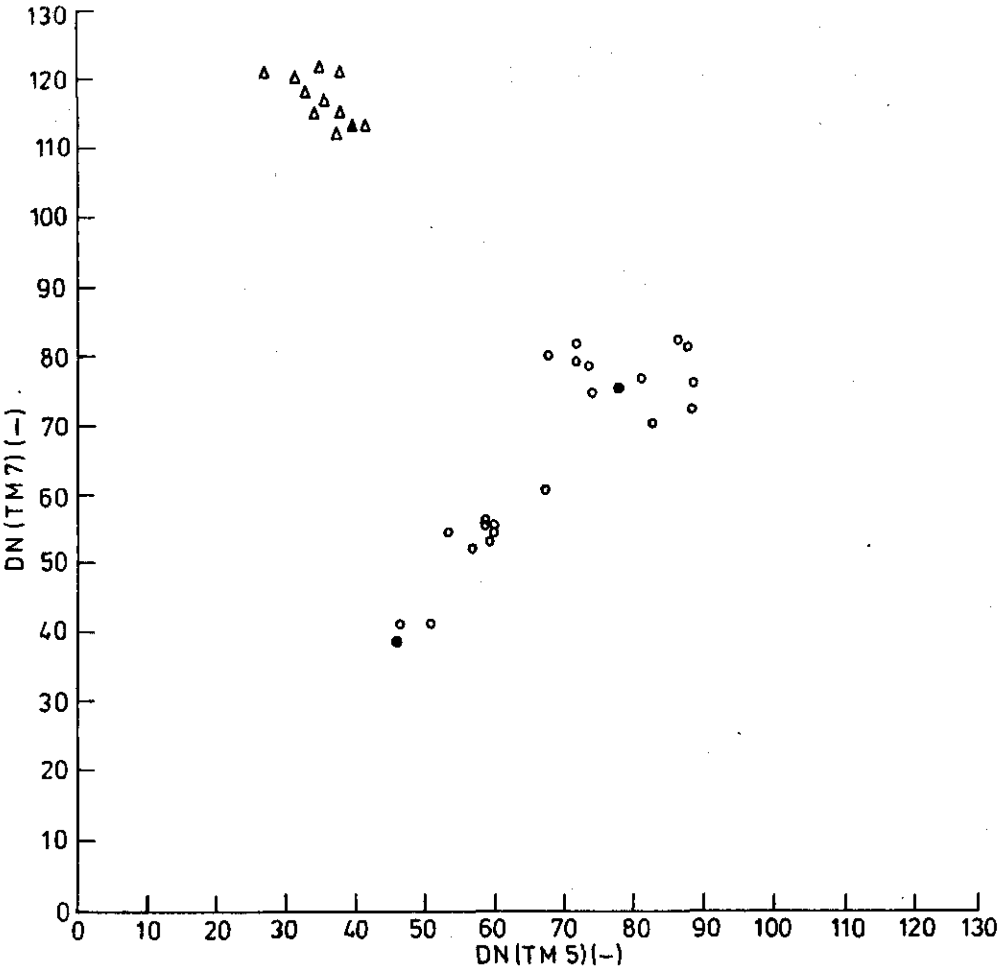

Fig. 1. Spectral bands ratio 7/5 relatives to bare soil area samples (o) and green stuff samples (Δ) of the East Sesia and Grande Bonifica Ferrarese irrigation districts
• bare soil ▲ green vegetation

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

2.1. Typical greenness, brightness and TVI values of crops

The typical crop vegetation indices values shown in Tables 1, 2 and 3 (AZZALI, 1985) have been modified by applying the new coefficients of the brightness and greenness formulae, as given in Chapter 1. We also calculated the values of vegetation indices corresponding to the characteristic growing stages of a particular crop. For this purpose we utilized mostly those literature data which are referring to reflectance

Table 1. 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 1' (after AZZALI, 1985)

Months	A_1	a_1	a_2	A_2	A_3	$\hat{a}_1$	B_1	B_2	C_1	D_1	E_1	F_1	G_1	H_1	J_1	K_1	I_1	I_2
April	3	50	45	0	-0.5	9.6	-2.3	-4.5	3	1.2	-6.7							-5
May	19.1	40	22	30	2.9	12.7	28.3	5.6	13	14.3	12.9							-3.5
June	21.4	12	12	24.7	38.2	22.7	30	36.1	18.5	20.5	21							3.5
July	18.1			5.3	23.5	48.3	0	7.2	21	18.6	11.9						31.7	27.5
August	11.3			-0.9	2.9	31.2	-0.9	2.1	5.7	5.2	9.5	19.4	23.3	17	27.9	16.6	33.2	28.6
September						9.6						45.3	41.5	21	39	38.6	26.5	

	L_1	M_1	m_1	N_1	N_4	N_2	N_3	N_5	O_1	O_2	O_3	P_1	Q_1	R_1	S_1	T_1	U_1
April	-5				-5			13.3	-4		13.8	4.3	-4.8	7.9	-4.5	-4.8	
May	-4				-0.9			13.3	-2		13.8	19.5	8.6	27.9	-1.9	-3.6	
June	10	23.4	22.8	23.7	20	24.4	24.2	15.8	1.7	27.2	16.9	27.6	30	26.2	0	0.5	
July	-3	24.2	23.05	32.7	31	24.2	23.9	44.8	23.5	29	57	25.5	28.8	24.8	20.5	31.7	41.2
August	4				17.1			47.6	26.5		61	13.6	0.5	1.4	23.6	20.7	15.8
September		26.2	22.9	29.2		24.1	22.5	30.2		21.8	28						

	V_1	W_1	Z_1
April			
May			
June			
July	46.1		33.2
August	40.4	9.7	
September	9.8	10.8	34.4

Table 2. 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 1' (after AZZALI, 1985)

Months	A_1	a_1	a_2	A_2	A_3	A_4	B_1	B_2	B_3	C_1	C_2	D_1	D_2	E_1	F_1	G_1	H_1	J_1
April	13.6	66.3	67	52.7	33.9		43.5	36.1	73	66		57.9		41				
May	30.7	61.9	65	71.5	47.5	43	71	55	61	66.7	57	62.6	61	59.5				
June	25.3	75.6	88	58.1	70.6	61	61.7	71.5	60	67	53	64.5	61	64.3				
July	22.7			47.3	53.2	54.2	57.4	59.1	74	60.7	50	65.9	61	52.1				
August	26.6			29.7	57.6	51	31.3	50	69	52.2	55	46.2	57	45.5	25.3	29.1	29.4	28.9
September						70			27		61		49		43.5	40	22.3	36

	K_1	I_1	I_2	L_1	M_1	m_1	N_1	N_4	N_2	N_3	O_1	O_2	P_1	Q_1	Q_2	R_1	S_1
April			36.5	35.5				35.5			40		53.6	39.1		62.1	51.9
May			47	50.7				42.3			43		62.1	56.9	70	65.5	53.8
June			53.5	53.1	42.7	42.7	47.6	49	42.5	40.8	48.5	42.9	65	61.4	54	63.8	53.3
July		34.2	67.4	35	45.4	41.7	42.1	62.4	42.3	39.6	59.3	41.9	63.8	56	49	69	64
August	23.5	32.2	62.7	36.2				48.3			53.5		62.9	43.6	31	44.3	55.7
September	35.6	27.1			56.3	42.6	60.8		48.3	72.5		70.4					

	T_1	U_1	V_1	W_1	Z_1
April	39				
May	44.1				
June	48.1				
July	69.5	48.2	47.7		37.2
August	58.6	26.5	40.4	35.4	
September			16.2	36.1	42.1

Table 3. 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 1' (after AZZALI, 1985)

Months	A_1	a_3	a_4	a_5	$\hat{a}_2$	X_1	X_2	C_3	C_4	D_3	E_2	E_3	F_1	G_1	H_1	J_1	K_1
April	0.89	1.11	1.17	0.89		0.70		0.95	0.96	0.5							
May	1.07	1.15	1	0.94	1.02	0.76	0.5	0.98	0.99	0.95	1						
June	1.15	1.03			0.85	1.06	0.89	0.95	0.94	1.13	0.99	0.71					
July	1.14				0.84	1.13	1.01	0.97	0.95	1.12	1.04	1.13					
August	0.98					1.15		0.97	0.96	1.02			1.12	1.12	1.06	1.19	1.10
September						1.03							1.22	1.21	1.17	1.22	1.22

	m_1	M_1	N_1	N_6	N_2	N_3	O_2	O_4	I_1	I_3	U_1	V_1	P_2	W_1	Z_1
April										0.44					
May				0.85				0.61		0.77			0.91		
June	1.06	1.06	1.06	1.03	1.07	1.08	1.08	0.64		1.11			0.89		
July	1.06	1.05	1.06	1.18	1.07	1.08	1.1	1.03	1.19	1.13	1.16	1.22	0.92		1.17
August				1.17					1.22	1.12	1.07	1.22		0.93	
September	1.07	1.02	1.02	1.03	1.05	0.97	0.95		1.21			1.06		0.92	1.13

measurements acquired in the four MSS wavelengths (0.5-0.6 μm; 0.6-0.7 μm; 0.7-0.8 μm; 0.8-1.1 μm) relating to the main characteristic crop growth stages. Crop growth stages were defined according to DOORENBOS and KASSAM (1979) while as crops we considered the main ones grown in the study areas and shown in Fig. 2 and Fig. 3 (after CLERMONT and MENENTI, 1984; respectively after AZZALI, 1985).

Data relating reflectance measurements with crop growth stages have been applied as given by UNGAR et al. (1977). Nevertheless, other sources of literature were utilized as it is shown in Appendix 1, list of codes 2, reference column. Then we calculated by applying the coefficients and the new literature data, the new values of greenness, brightness and TVI for several crops.

Therefore relating the characteristic growth stages of the main crops in the two irrigation districts to their crop calendars (Figs. 2 and 3), the progression of the vegetation indices was obtained as a function of time. Tables 4, 5 and 6 show the modified 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.

If we compare the winter wheat greenness and brightness values respectively in Tables 4 and 5 column A1 (source: UNGAR et al., 1977) with winter wheat greenness and brightness values calculated again from UNGAR et al. (1977) but applying the formulae applied for Tables 1 and 2, large differences, especially as regards greenness, are pointed out

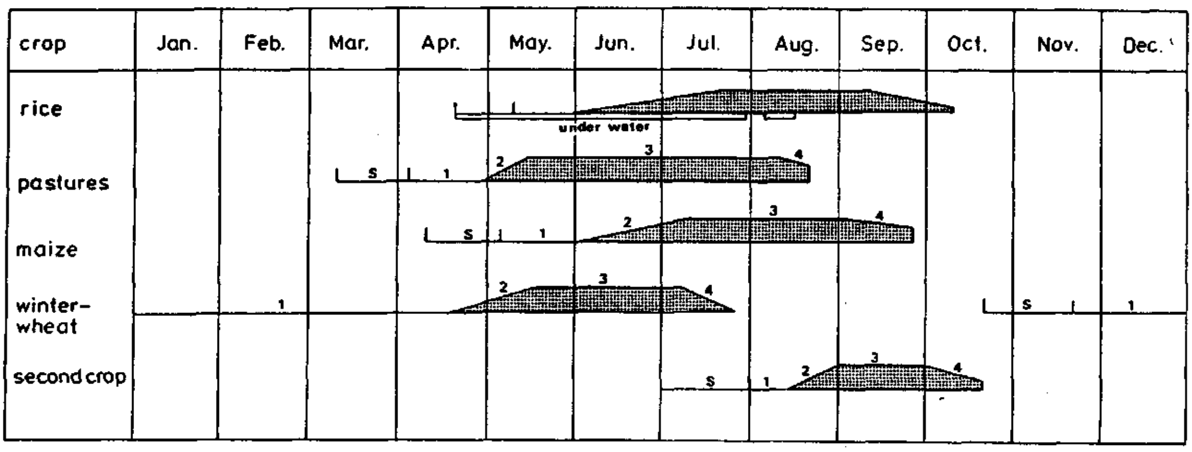

Fig. 2. Crop calendar for main crops, grown in East Sesia and Villoresi S-1-2-3-4: growth stages according to Clermont and Menenti (1984) (after CLERMONT and MENENTI, 1984)

Table 4. 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 2"

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 5. 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 2"

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 6. 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 2'

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

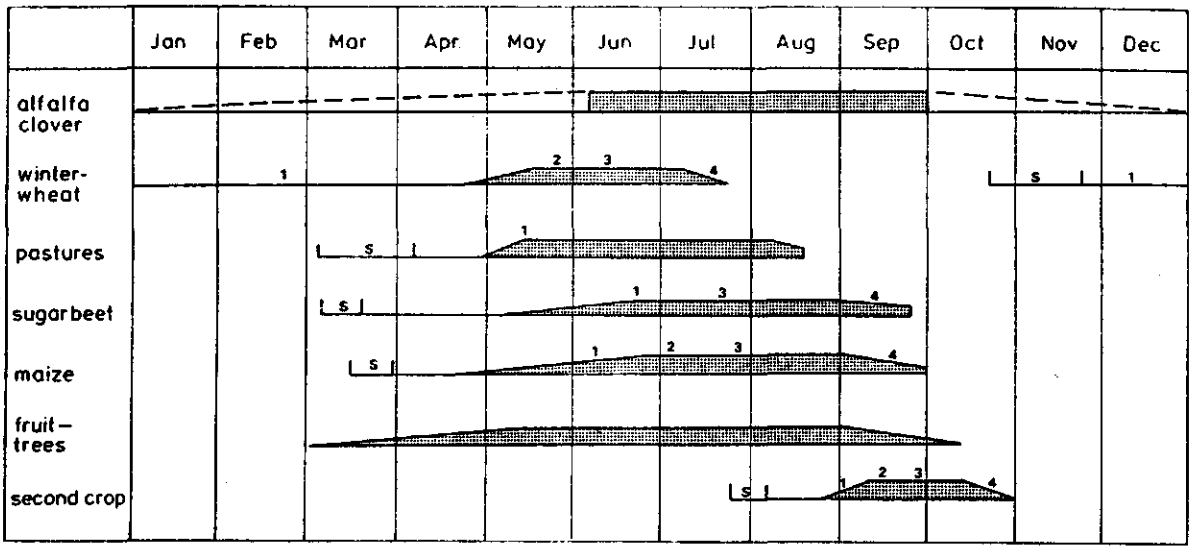

Fig. 3. Modified crop calendar for the year 1980 - Grande Bonifica Ferrarese and Navarolo
S-1-2-3-4: growth stages according to Doorenbos and Kassam (1979) (after AZZALI, 1985)

in Table 7.

Table 7. Greenness and brightness values of winter wheat from April till July calculated by means of greenness and brightness formulae (A. Greenness and brightness formulae, after AZZALI, 1985; B. eqs. (1) and (2), this report)

Source reflectance for winter wheat: UNGAR et al., 1977

	GR_A	GR_B	BR_A	BR_A
April	49.8	37.0	47.7	45.2
May	45.0	31.3	48.4	45.6
June	33.4	23.7	46.0	32.9
July	15.1	4.0		

Then, the use of different coefficients in the brightness and greenness formulae gave different results.

2.2. The multi-temporal - multi-index method applied to the two irrigation districts

Figs. 4a and 5a show the new crop discrimination schemes for East Sesia respectively Grande Bonifica Ferrarese irrigation districts by applying the multi-index method which used the vegetation indices values collected in Tables 4, 5 and 6. In Figs. 4b and 5b the crop discrimination schemes earlier applied by AZZALI (1985) for the same irrigation districts are given. Comparing Fig. 4a with Fig. 4b and Fig. 5a with Fig. 5b, we notice that a different crop discrimination scheme has been obtained when calculating the greenness and brightness values by means of the previous respectively new coefficients.

Concerning the East Sesia irrigation district, we are able, for example, to discriminate rice by means of brightness in April as Fig. 4a shows, while, previously, rice was discriminated in April by means of greenness as Fig. 4b shows. Nevertheless, both Figs. 4a and 4b show indeed that crops in the East Sesia can be discriminated by applying the April image only, provided the discrimination between pasture and haygrass is not required.

Regarding the Grande Bonifica Ferrarese irrigation district, Fig. 5a shows winter wheat discrimination by means of greenness in May, while the same crop was previously discriminated by means of TVI in May as Fig. 5b shows. In addition, Fig. 5a shows rice discrimination in the Grande Bonifica Ferrarese. This crop was not previously considered as Fig. 5b shows. Nevertheless, it should be pointed out that in the Grande Bonifica Ferrarese corn is discriminated by means of greenness in May in both Fig. 5a and Fig. 5b.

The actual cultivated areas for East Sesia respectively Grande Bonifica Ferrarese irrigation districts are given in Table 8 respectively 9 (AZZALI, 1985) and they will be applied as reference terms to evaluate the results presented in Tables 10 and 11. These tables show the estimated area for each crop as obtained by applying the multi-index discrimination scheme presented respectively in Fig. 4a and 5a.

As regarding the East Sesia irrigation district, the comparison between the percentage of crop cultivated area in Table 8 and 10 suggests the following remarks:

- rice cultivated area detected by means of brightness in April is 8.6% underestimated;

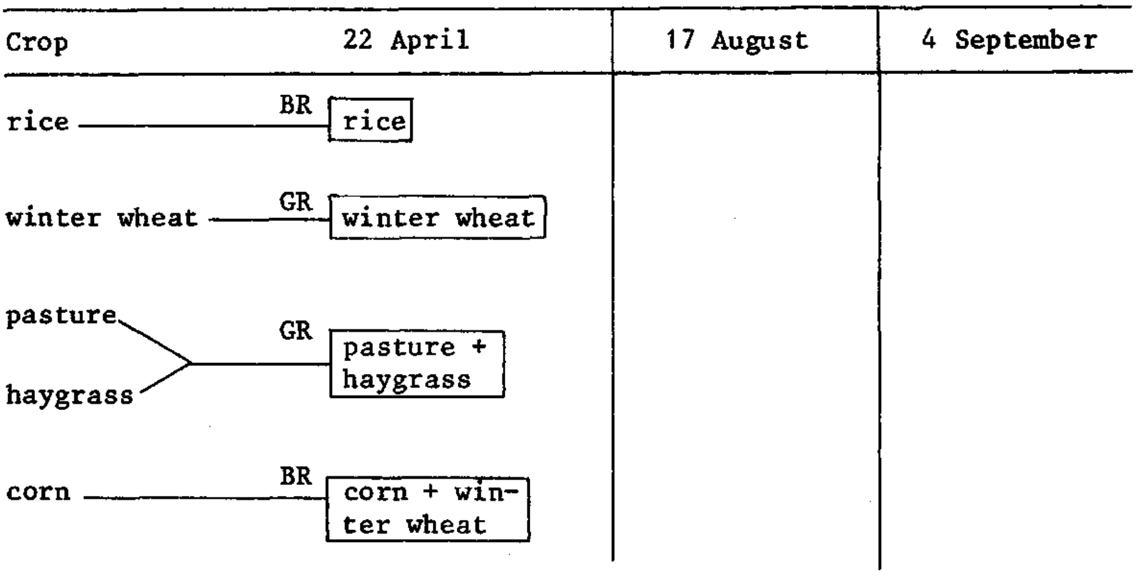

Fig. 4a. East Sesia, image 209.29. Available dates: 22 April, 17 August and 4 September 1980. Crop discrimination by the combined use of three vegetation indices

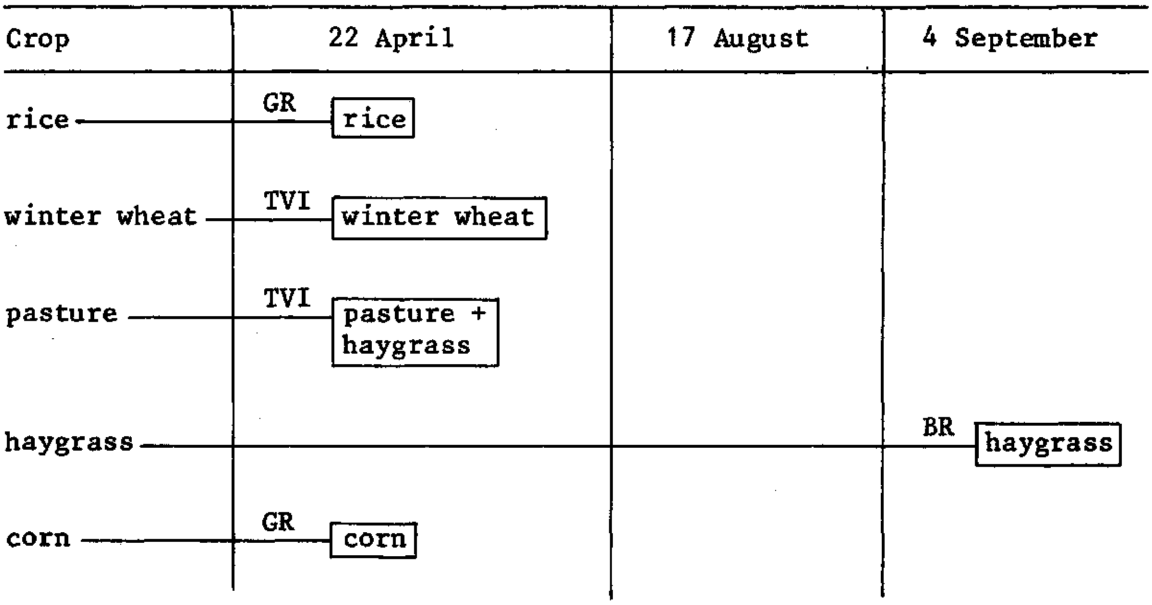

Fig. 4b. East Sesia - Villoresi, image 209.29. Available dates: 22 April, 17 August and 4 September 1980. Crop discrimination by the combined use of three vegetation indices (after Azzali, 1985)

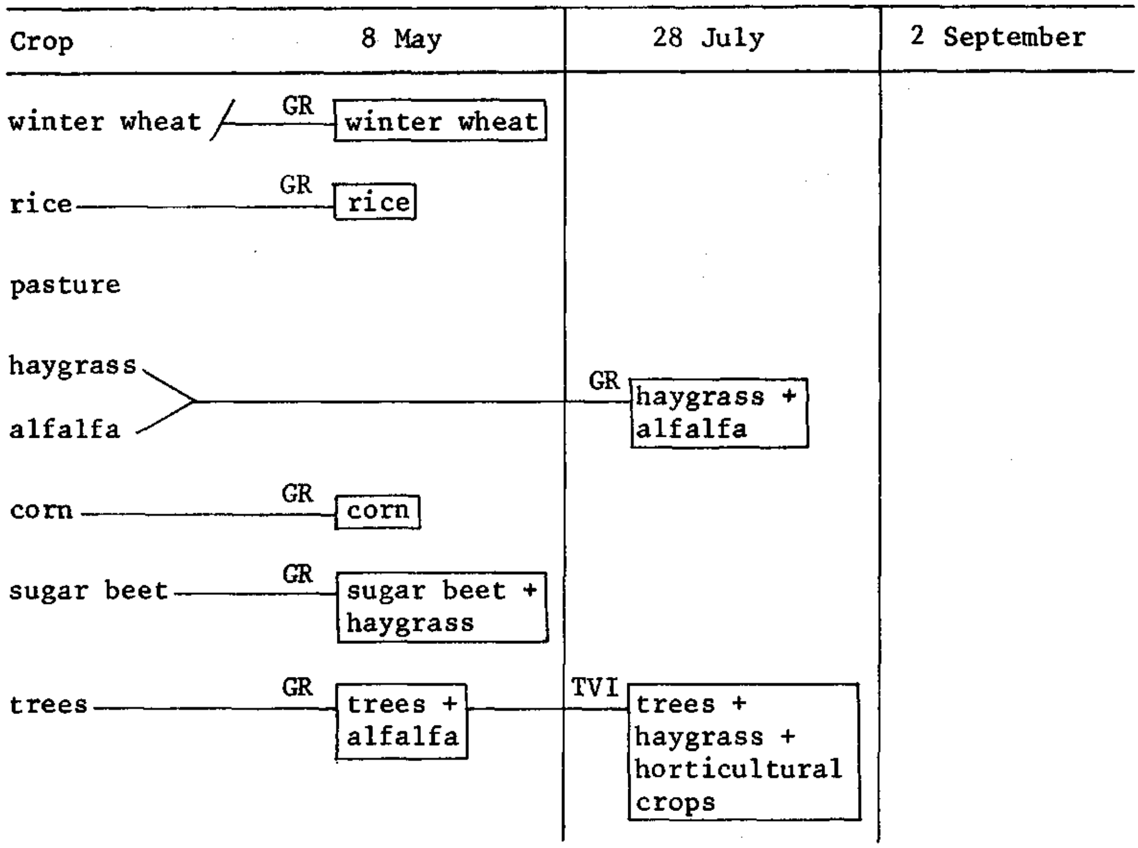

Fig. 5a. Grande Bonifica Ferrarese, image 207.29. Available dates: 8 May, 28 July and 2 September. Crop discrimination by the use of three vegetation indices

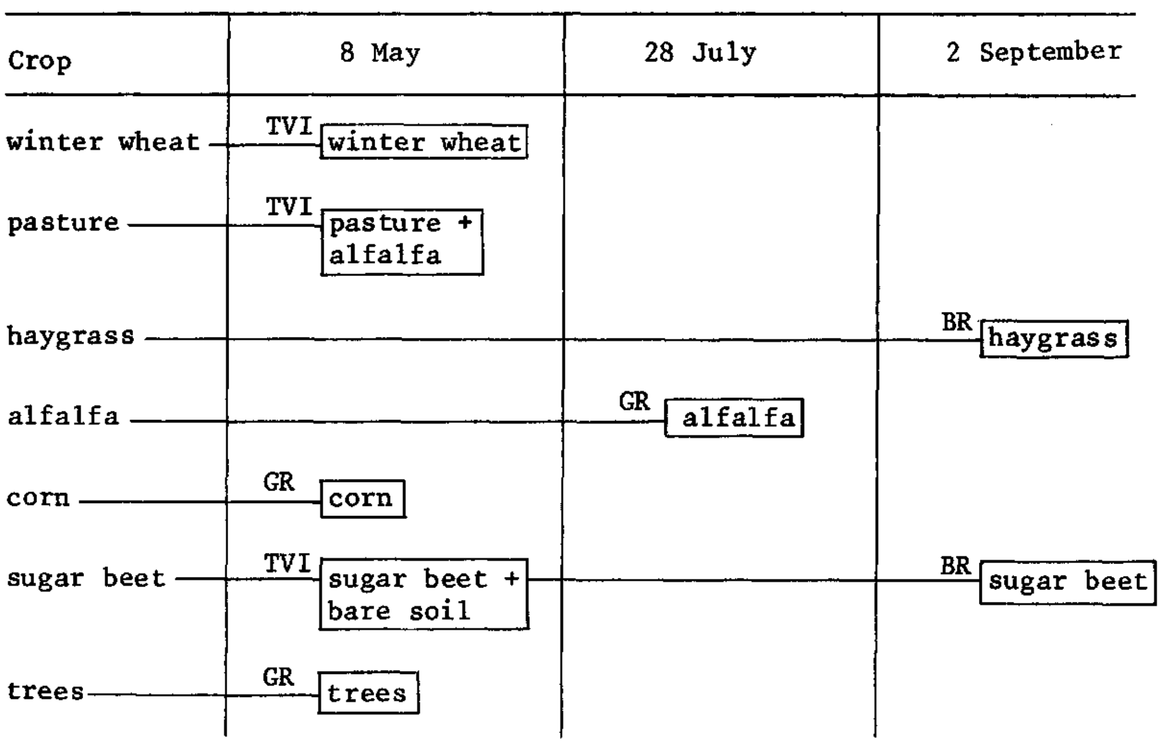

Fig. 5b. Grande Bonifica Ferrarese, image 207.29. Available dates: 8 May, 28 July and 2 September. Crop discrimination by the use of three vegetation indices (after Azzali, 1985)

Table 8. Cultivated area as percentage of the area of three 'zone agrarie' no. 11, 12, 13 belonging to Novara province for five main crops cultivated in East Sesia, as estimated on the basis of ISTAT data collected for the 1980 farming year (after ISTAT, 1982)

Crops	Cultivated area relative to 'zone agrarie' (%)
rice	32.4
haygrass	32.1
corn	24.3
pasture	11.5
winter wheat	6

Table 9. Cultivated area as percentage of the total agricultural area of Ferrara province for the 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 territorial (%)
winter wheat	23
haygrass alfalfa	14.5
pasture	0.03
corn	8
sugar beet	20
trees	11.9
rice	2.8
tomato	1.3
horticultural crops	4.6

Table 10. Characteristic crop interval (a,b) of greenness, brightness and transformed vegetation index; crop cultivated area as percentage of the total territorial area by means of the multitemporal multi-index method; only the values required by the discrimination scheme of Fig. 4a are shown - East Sesia

Crops	April						August						September					
	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%
Rice			(15,36)	29.6														
Haygrass / Pasture	(12,16)	47.9																
Corn			(42,51)	28.5														
			28.5-6.5 = 22															
Winter wheat	(27,33)	6.5																

Table 11. Crop characteristic interval (a,b) of greenness, brightness and transformed vegetation index; crop cultivated area (as percentage of the total territorial area), as estimated by means of the multi-temporal multi-index method; only the values required by the discrimination scheme of Fig. 5a are shown - Grande Bonifica Ferrarese

Crops	May						July						September					
	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%
Winter wheat	(25,43)	20.5																
Alfalfa Haygrass							(17,21)	21.5										
Corn	(3,7)	9.2																
Sugarbeet	(10,16)	32.9																
	32.9-16.8 =	16.1																
Trees	(17,23)	20.8																
	20.8-4.7 =	16.1																
Rice	(-4,0)	3.3																

- winter wheat cultivated area detected by means of greenness in April is 8% overestimated;
- corn cultivated area detected by means of brightness in April is 9% underestimated. Fig. 4a shows that the characteristic interval of brightness value in April which defines corn, defines also winter wheat. Nevertheless, having already discriminated winter wheat by means of greenness, the difference between the percentage of winter wheat area (6.5%) minus the percentage of corn and winter wheat by means of brightness (28.5%) gives the percentage of corn cultivated area (22%);
- haygrass plus pasture cultivated areas as detected by means of greenness in April are overestimated by 10%.

Then in the East Sesia irrigation district five out of five crops were properly detected by means of the multi-temporal - multi-index method.

Regarding the Grande Bonifica Ferrarese irrigation district, the comparison between the percentage of crop cultivated areas shown in Table 9 respectively Table 11 drives to the following conclusions:

- winter wheat cultivated area detected by means of greenness in May is 11% underestimated;
- rice cultivated area detected by means of greenness in May is 18% overestimated;
- corn cultivated area detected by means of greenness in May is 15% overestimated;
- haygrass together with alfalfa cultivated areas detected by means of greenness in July is 48% overestimated;
- trees cultivated areas can be detected respectively by means of greenness in May and by means of TVI in July as Fig. 5a shows. In both the discrimination choices the characteristic vegetation indices interval of trees is also the same as for alfalfa and for haygrass plus horticultural crops.

  Considering a system of 3 equations having three unknowns, we calculate the percentage of trees cultivated area in the following way:

$$x + y = 21.5 \tag{3}$$

where x is the haygrass and y the alfalfa cultivated area as obtained by means of greenness in July

$$z + y = 20.8 \quad (4)$$

where z is the trees and y the alfalfa cultivated area as obtained by means of greenness in May

$$z + x = 38.8 - 5.9 \quad (5)$$

where z is the trees and x the haygrass cultivated area as obtained by means of TVI in July; the value of 5.9 represents the percentage of horticultural crops plus tomato cultivated areas taken from Table 9.

Solving the system of three eqs. (3), (4) and (5):

x = percentage of haygrass cultivated area = 16.8%

y = percentage of alfalfa cultivated area = 4.7%

z = percentage of trees cultivated area = 16.1%

Comparing the percentage of trees cultivated area (16.1%) obtained by solving the system with the percentage of trees cultivated area in Table 9 (11.9%), then the calculated trees cultivated area is 35.3% overestimated;

- sugar beet can be detected by means of greenness in May; this characteristic greenness interval is also the same for haygrass as Fig. 5a shows.

  If we consider the percentage of haygrass cultivated area previously obtained by means of eqs. (3), (4) and (5) which is 16.8%, then the difference between the percentage of haygrass area (16.8%) minus the percentage of sugar beet and haygrass by means of greenness (32.9%) gives the percentage of sugar beet cultivated area (16.1%), which is 19.5% underestimated compared with the percentage of sugar beet cultivated area shown in Table 9.

  The underestimation of the sugar beet cultivated area is, in this case, caused by the overestimation of haygrass cultivated area.

Then, even if only four out of seven crops were properly detected in the Grande Bonifica Ferrarese irrigation district, we should mention that the big overestimation of haygrass and alfalfa cultivated areas strongly affected the wrong estimations of trees respectively sugar beet cultivated areas.

2.3. Conclusions

The multi-temporal multi-index method has been improved by applying the vegetation indices formulae with new coefficients calculated for the study areas.

According to HALL (1984), variations of the values of reflectances measured in the four bands of MSS show up as soon as the type of soil changes, even if the same vegetation cover is considered. This implies that the coefficients in the greenness and brightness formulae are soil type dependent. The use of the new coefficients in the brightness (1) and greenness formulae (2) gave crops typical values of these two vegetation indices (Tables 4 and 5) which are different from those in Tables 1 and 2. Furthermore, the use of the crop typical greenness and brightness values shown in Tables 4 and 5 gave different crop discrimination schemes as compared with those presented earlier by AZZALI (1985).

The results acquired by means of the multi-temporal - multi-index method analysed in Chapter 10 in the previous report (AZZALI, 1985) respectively in Section 2.2 of this report will now be compared. We call the multi-temporal - multi-index method applied in the previous report version A, while the same method with new coefficients for brightness and greenness formulae applied in this report version B.

In the East Sesia irrigation district, since the crop discrimination by means of the multi-temporal - multi-index method was already possible with only one image (the April image), more accurate estimates of rice and winter wheat cultivated areas was performed by the means of the method version B. Furthermore, good estimates were obtained for corn and fodder crops cultivated areas by means of method version B. The good performance of the method version A has to be attributed to the use for crop discrimination of typical crop values of TVI, which values are independent from the specific soil line. Even few crop brightness and greenness values taken from Tables 1 and 2 and used in method version A performed rather well because those values were not, by chance, far from the same crop values calculated by means of the method version B.

Some remarks about the reference data shown in Table 8 should be mentioned. Such reference data (Table 8) refer, as regards the East Sesia, to three 'zone agrarie' (for the meaning of 'zone agrarie', see AZZALI, 1985), no. 11, 12 and 13, which are the 85% of the territory portion of the entire MSS frame. These reference data are also referring to a cultivated area in which 90% of the crops were grown. The portion of the East Sesia irrigation district shown in the considered LANDSAT 2-MSS images occupies a big part of these three 'zone agrarie' (no. 11, 12 and 13), which means that the reference data applying to the three zone agrarie closely relate to the portion of East Sesia irrigation district considered in this report.

As regards the Grande Bonifica Ferrarese irrigation district, the multi-temporal - multi-index method version A gave good crop discriminations and accurate evaluation of the percentage of cultivated areas regarding trees, sugar beet, alfalfa and haygrass, while uncorrect evaluations of winter wheat and corn cultivated areas occurred.

With the same method version B, the estimation of cultivated areas was rather accurate for winter wheat, corn and rice while the percentages of cultivated areas for trees, sugar beet, haygrass and alfalfa were not correct.

Evidence of reflectance discriminations between crops is shown in Table 12 where crops are characterized by typical vegetation index interval of values in Grande Bonifica Ferrarese. Similar evident discriminations are also shown in Table 11. Crops as winter wheat, corn, rice, haygrass plus alfalfa are undoubtedly rather well characterized by their typical intervals of vegetation index values (Table 11). Even if sugar beet and trees intervals of typical greenness values are very close between each other (see Table 11), these crops can be discriminated by the others as the procedure in Section 2.2 has shown.

Nevertheless, even though in both version A and B the spectral characteristics are rather representative for each crop in Grande Bonifica Ferrarese, the calculation of some crop cultivated areas as percentage of the total territorial area gave some inaccurate results when we compared the calculated percentage to the reference data shown in Table 9.

These findings can be explained by taking into account the poor accuracy of the reference data of Grande Bonifica Ferrarese (Table 9).

Table 12. Crop characteristic interval (a,b) of greenness, brightness and transformed vegetation index; crop cultivated area (as percentage of the total territorial area), as estimated by means of the multi-temporal multi-index method - Grande Bonifica Ferrarese, version A (after AZZALI, 1985)

Crops	May						July						September					
	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%
Winter wheat					(1.03,1.13)	12.4												
Alfalfa							(10,13)	12.2										
Haygrass															(44,54)	2.1		
Corn	(5,7)	15.6																
Sugarbeet					(0.72,0.81)	19.5									(24,30)	39.4		
Trees	(17,21)	11.9																

These reference data give the extent of the crop areas in the entire province of Ferrara, while the Grande Bonifica Ferrarese irrigation district occupies the 27% only of the territorial area of Ferrara province. Moreover, in the Ferrara province some crops as corn and winter wheat are evenly cultivated all over the territory because they are not influenced by specific agronomic constraints. On the other hand, crops like rice, sugar beet, trees, fodder crops, bound to specific agronomic constraints (soil type, water table depth, presence of dairy cattle, etc.) will show an uneven distribution all over the cultivated area of Ferrara province. Then, the distribution of certain crops inside the irrigation district is not similar to that of the whole territory of Ferrara province. So, the applied method version B did not give accurate estimations of cultivated area for those crops, as trees, sugar beet and fodder crops, which are unevenly spread in the province of Ferrara. Also rice is unevenly cultivated in Ferrara province but, by chance, the territory of Grande Bonifica Ferrarese irrigation district is the only area in the whole province in which rice is cultivated. Then, the good discriminations regarding rice, winter wheat and corn were achieved by the applied method version B using the reference data shown in Table 9, while to properly assess the accuracy for those crops unevenly distributed on the territory of Ferrara province, more detailed reference data should be available.

Unfortunately, it is impossible to find a more detailed record (for the year 1980) of the pattern of agricultural area crop distribution for Grande Bonifica Ferrarese than that shown in the reference data in Table 9.

As general conclusions we can say that in the East Sesia irrigation district, the results obtained by means of both method version A and B give us the possibility to set up the map of crop distribution regarding the year 1980. Less accurate results (with few gross misestimates) were obtained for the Grande Bonifica Ferrarese irrigation district, although the accuracy of the reference data is doubtful.

The applied technique was successful till the available reference data were accurate. Consequently, the main point of the research which needs a further improvement is the quality of the reference data.

To this purpose we will apply the multi-temporal - multi-index method

- with new images of LANDSAT Thematic Mapper (TM), in the year 1985;
- in the East Sesia and Grande Bonifica Ferrarese irrigation districts;
- with collection of field data concerning the location of several field plots of the main cultivated crops during 1985

in order to assess the accuracy of the crop maps obtained from LANDSAT data.

The mapping of probable water stress of crops by means of the multi-temporal - multi-index method and the collection of 1985 meteorological data in the analysed study areas will also be included in the work plan for the period October 1985 to October 1986.

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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.

AZZALI, S. 1985. 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. Nota 1611 ICW, Wageningen, The Netherlands.

BADHWAR, G.D. 1984. Use of LANDSAT-derived profile features for spring small-grains classification. Int. J. Remote Sens. 5.5: 783-797.

CASALICCHIO, G. et al. 1974. Carta dei suoli dell'Emilia e Romagna. Regione Emilia Romagna, Servizio cartografico e dei suoli.

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

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

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.

HUETE, A.R., D.F. POST and R.D. JACKSON. 1984. Soil spectral effects on 4 space vegetation discrimination. Remote Sens. Environ. 15: 155-165.

ISTITUTO nazionale per piante da legno 'G. Piccarolo', IPLA, Torino. 1979. Regione Piemonte. Carta della capacitá d'uso dei suoli e delle loro limitazioni. Regione Piemonte. Assessorato alla pianificazione del territorio e di parchi naturali.

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 Sens. Environ. 13: 187-208.

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

KAPLAN, W. 1984. Advanced calculus. Third Edition. Addison-Wesley Publishing Company. 721 pp.

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:41-50.

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.

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

PINTER, P.J. Jr., R.D. JACKSON, S.B. IDSO and R.J. REGINATO. 1981. Multidate spectral reflectance as predictors of yield in water stressed wheat and barley. Int. J. Remote Sens. 2.1: 43-48.

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: 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. Int. J. Remote Sens. 4.2: 325-334.

TUCKER, C.J., J.H. ELGIN, J.E. McMURTREY and C.J. FAN. 1979. Monitoring corn and soybean crop development with hand-held radiometer spectral data. Remote Sens. Environ. 8: 237-248.

TUCKER, C.J., J.H. ELGIN and J.E. McMURTREY. 1980. Relationship of crop radiance to alfalfa agronomic values. Int. J. Remote Sens. 1.1: 69-75.

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. Machine processing of remotely sensed data symposium: 394-401.

LIST OF CODES 1

Codes of the crop-data-sets considered in Tables 1, 2 and 3 (after AZZALI, 1985)

Code	Crop Data Set	Reference
A_1	spring wheat	Miller et al. (1984)
A_2	spring wheat early plant	Johnson (1981)
A_3	spring wheat late plant	Johnson (1981)
A_4	spring wheat	Badhwar (1984)
a_1	winter wheat var. Produra well watered	Jackson et al. (1983)
a_2	winter wheat var. Produra stressed	Jackson et al. (1983)
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)
$\hat{a}_1$	small grains	Hall and McDonald (1983)
$\hat{a}_2$	small grains	Wood and Beck (1982)
B_1	barley early plant	Johnson (1981)
B_2	barley late plant	Johnson (1981)
B_3	barley	Badhwar (1984)
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)
F_1	perennial ryegrass	Van Kasteren and Uenk (1975)
G_1	mixed grass	Van Kasteren and Uenk (1975)
H_1	quackgrass	Van Kasteren and Uenk (1975)

J_1	meadowgrass	Van Kasteren and Uenk (1975)
K_1	red fescue	Van Kasteren and Uenk (1975)
I_1	sugar beet	Van Kasteren and Uenk (1975)
I_2	sugar beet	Johnson (1981)
I_3	sugar beet	Clermont and Menenti (1984)
L_1	idle fallow	Johnson (1981)
M_1	sorghum	Purdue Bulletin (1969)
m_1	sudan grass	Purdue Bulletin (1969)
N_1	corn	Purdue Bulletin (1969)
N_2	corn var. Pfister 5 x 29	Purdue Bulletin (1969)
N_3	corn var. Pfister 5 x 9	Purdue Bulletin (1969)
N_4	corn	Johnson (1981)
N_5	corn	Badhwar et al. (1982)
N_6	corn	Clermont and Menenti (1984)
O_1	soybeans	Johnson (1981)
O_2	soybeans	Purdue Bulletin (1969)
O_3	soybeans	Badhwar et al. (1982)
O_4	soybeans	Tucker et al. (1979)
P_1	trees	Johnson (1981)
P_2	orchard	Wood and Beck (1982)
Q_1	oat	Johnson (1981)
Q_2	oat	Badhwar (1984)
R_1	winter rye	Johnson (1981)
S_1	millet	Johnson (1981)
T_1	sunflowers	Johnson (1981)
U_1	beans	Van Kasteren and Uenk (1975)
V_1	potatoes	Van Kasteren and Uenk (1975)
W_1	stubble (corn residue)	Seeley et al. (1983)
Z_1	vineyard var. Sangiovese	Martini and Sciarretta (1977)
X_1	rice	Clermont and Menenti (1984)
X_2	rice	Wood and Beck (1982)

LIST OF CODES 2

Codes of the crop-data-sets considered in Tables 4, 5 and 6

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 2 - MSS PRODUCTS

Colour coded image on photo 1 is obtained by taking the multispectral image of brightness on April 22 and assigning the blue colour to the interval in which rice is discriminated from the other crops by means of brightness in April. Furthermore, the green and the red colours have been assigned to the values upper and lower boundaries belonging to the interval of corn discrimination by means of brightness.
Note: the brightness characteristic interval of corn in the image is between 42 and 51. Corn has as confusion crop winter wheat which intrudes in the corn characteristic brightness interval in the values between 49 and 51. In the image the red colour denotes the brightness interval between the values 49 and 51 which belong both to corn and winter wheat, while the green colour denotes the interval of brightness between values 42 and 48 which discriminate part of corn cultivated area from the other crops.

Colour coded image on photo 2 is obtained taking the multispectral image of greenness on April 22 and assigning the green colour to values within the characteristic interval of winter wheat and the red colour to values within the characteristic interval of haygrass and pasture.

Colour coded image in photo 3 has been obtained by calculating the difference between the multispectral image of brightness on April 22 and the multispectral image of greenness on the same date. Then, the green colour was assigned to the values within the corresponding characteristic interval of the difference between the brightness values of corn plus winter wheat in April minus the characteristic greenness values of winter wheat in April. This procedure to discriminate corn from the other crops is explained at page 20 of this report.

Colour coded image in photo 4 is obtained by taking the multispectral image of greenness on May 8 and assigning the red colour to the interval in which winter wheat is discriminated from the other crops by means of greenness. Furthermore, assigning the green colour to the interval in which corn is discriminated from the other crops by means of greenness. Then the blue colour was assigned to the interval in which rice is discriminated from the other crops by means of greenness. The greenness interval between the values 17 and 23 is denoted by the yellow colour, such interval of greenness values denotes trees plus a portion of alfalfa cultivated area. The violet colour was assigned to the greenness interval between the values 10 and 16 which denote sugar beet plus a portion of haygrass cultivated area.

Colour coded image on photo 5 is obtained taking the multispectral image of greenness on July 28 and assigning the red colour to the interval in which haygrass plus alfalfa are discriminated from the other crops by means of greenness in July.