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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

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1. INTRODUCTION

The purpose of this research is to assess the feasibility of a method to determine quality, quantity and type of crops and to assess their probable water stress by means of LANDSAT-images. The practical application of this method will be tested by means of LANDSAT-images in two study-areas, which are irrigation districts located in the Po valley, Italy, namely: East Sesia-Villoresi and Grande Bonifica Ferrarese.

In an actual case reference data are necessary in order to know which crops are growing where and, therefore, to establish their spectral features during the growing season. The research challenge is to detect the actual difficulties to be overcome selecting and tuning an interpretation method.

Few vegetation indices are able to discriminate some crops by looking at spectral reflectances in certain bands, so the assessment of crop water stress through the same method presents additional difficulties. Computation of 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 ones remain: JACKSON (1982), PINTER (1982) and HATFIELD (1983).

Both approaches require crop identification as a first step, e.g. by means of different vegetation indices eventually applied in a combined manner. In principle the best vegetation index to detect water stress will be that which is not sensible to crop type, being such variation a disturbance factor in the proceeding of the actual stress detection.

The performance of each vegetation index with respect to crop discrimination and crop water stress detection will be pointed out. Moreover, the possibility of improving the performance of the various vegetation indices, by applying them in a combined manner, will be evaluated in this report.

2. CHOOSING THE VEGETATION INDICES

Many vegetation indices have been proposed to study vegetation characteristics by means of satellite data. Greenness (green vegetation) and brightness (soil brightness) by denomination of KAUTH and THOMAS (1976) are two vegetation indices. Taking into account the four channels of the Multispectral Scanner (MSS) sensor on board the LANDSAT satellites in the following wavelenghts 0.5-0.6 μm (MSS4), 0.6-0.7 μm (MSS5), 0.7-0.8 μm (MSS6), 0.9-1.1 μm (MSS7). In literature, a wealth of greenness and brightness values is given as relating to many crops and growth stages.

The formulae expressing greenness and brightness are:

$$\text{Brightness} = 0.33231\ \text{MSS4} + 0.60316\ \text{MSS5} + 0.67581\ \text{MSS6} + 0.26278\ \text{MSS7}$$

$$\text{Greenness} = -0.28317\ \text{MSS4} - 0.66006\ \text{MSS5} + 0.57735\ \text{MSS6} + 0.38833\ \text{MSS7}$$

The suitability of these two indices to detect the different crop development stages and the availability of literature data make worthwhile their selection as suitable vegetation indices for our purpose. Moreover, another vegetation index is considered. The transformed vegetation index TVI (ROUSE et al., 1973) is considering two bands, MSS5 and MSS7 of the LANDSAT-MSS.

Briefly, the TVI formula is:

$$\text{TVI} = \left(\frac{\text{MSS7} - \text{MSS5}}{\text{MSS7} + \text{MSS5}} + 0.5\right)^{\frac{1}{2}}$$

The reason of selection of TVI index in our research has to be attributed to a previous study (CLERMONT and MENENTI, 1984) which focussed the TVI assessment for many crops along their own growing season and for the same area, subject of our study. The TVI has the advantage of being sensitive to green vegetation, while it shows little sensitivity to atmospheric attenuation, so making images on different dates more easily comparable with each other.

3. LITERATURE DATA ABOUT GREENNESS, BRIGHTNESS AND TVI

A large number of data has been presented in the literature referring to a number of crops, to their reflectance in the following four bands (0.5-0.6 μm; 0.6-0.7 μm; 0.7-0.8 μm; 0.8-1.1 μm) and to values of greenness and brightness indices for some of those crops.

The literature showed quite a large variation in greenness and brightness values. The following scheme summarizes the variations due mostly to the coefficients in the formula applied by different researchers:

1) KAUTH and THOMAS (1976); THOMPSON and WEHMANEN (1979)

$$BR = 0.4326\ MSS4 + 0.6325\ MSS5 + 0.5857\ MSS6 + 0.2641\ MSS7$$

$$GR = -0.2897\ MSS4 - 0.5620\ MSS5 + 0.5995\ MSS6 + 0.4907\ MSS7$$

2) RICE et al. (1980); KOLLENKARK et al. (1982); HATFIELD et al. (1984)

$$BR = 0.3236\ MSS4 + 0.4852\ MSS5 + 0.5663\ MSS6 + 0.6095\ MSS7$$

$$GR = -0.4894\ MSS4 - 0.6125\ MSS5 + 0.1729\ MSS6 + 0.5954\ MSS7$$

3) JACKSON et al. (1983); JOHNSON (1981)

$$BR = 0.33231\ MSS4 + 0.60316\ MSS5 + 0.67581\ MSS6 + 0.26278\ MSS7$$

$$GR = -0.28317\ MSS4 - 0.66006\ MSS5 + 0.57735\ MSS6 + 0.38833\ MSS7$$

4) BADHWAR (1984)

$$BR = 0.332\ MSS4 + 0.63\ MSS5 + 0.59\ MSS6 + 0.26\ MSS7$$

$$GR = -0.283\ MSS4 - 0.66\ MSS5 + 0.577\ MSS6 + 0.381\ MSS7$$

The coefficients of the above written equations have been calculated by taking into account the dependence on the calibration factors of each sensor, and not, as should be, on the variability of the soil reference line for each particular area. The latter implies that the calculation of greenness and brightness can give some spurious variation of greenness and brightness.

In order to make comparable the acquired data with each other, one standard formula for each vegetation index was used. The adopted greenness and brightness formulae were those given by JACKSON (1983).

The adopted TVI formula was that given by ROUSE et al. (1973).

Table 1 shows the whole set of collected data for greenness vegetation index concerning several crops and applying to the period April through September. For the explanation and data sources of Table 1 see the 'List of codes'. Table 2 shows the set of collected data for brightness vegetation index concerning several crops and applying to the same period as Table 1; for crop codes see 'List of codes'. Table 3 presents TVI-values for several crops and relating to the period April through September.

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'

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'

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'

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

4. STUDY AREAS AND THEIR CROP CALENDAR

The LANDSAT images to be analysed concern the area of East Sesia - Villoresi (Italy) (frame 209.29), acquired on the following dates: April 22, August 17 and September 4, 1980; and the area of Grande Bonifica Ferrarese - Navarolo (Italy) (frame 207.29), acquired on the following dates: May 8, July 28 and September 2, 1980.

A previous research (CLERMONT and MENENTI, 1984) dealing with the same study areas, pointed out a close relationship between the TVI vegetation index and vegetation growth. The same research has also, previously, developed detailed crop calendars, as Figs. 1 and 2 show, for these study areas.

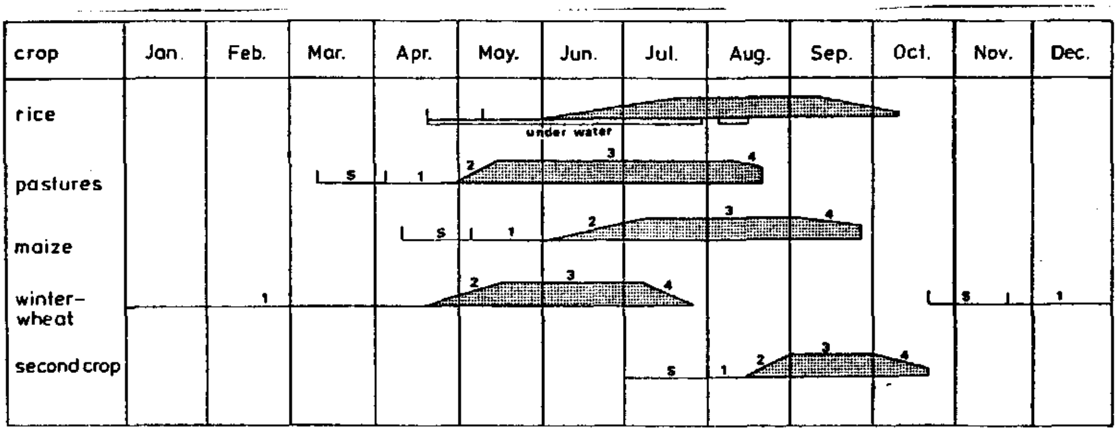

Fig. 1. Crop calendar for main crops, grown in East Sesia and Villoresi S-1-2-3-4: growth stages according to FAO (1979)

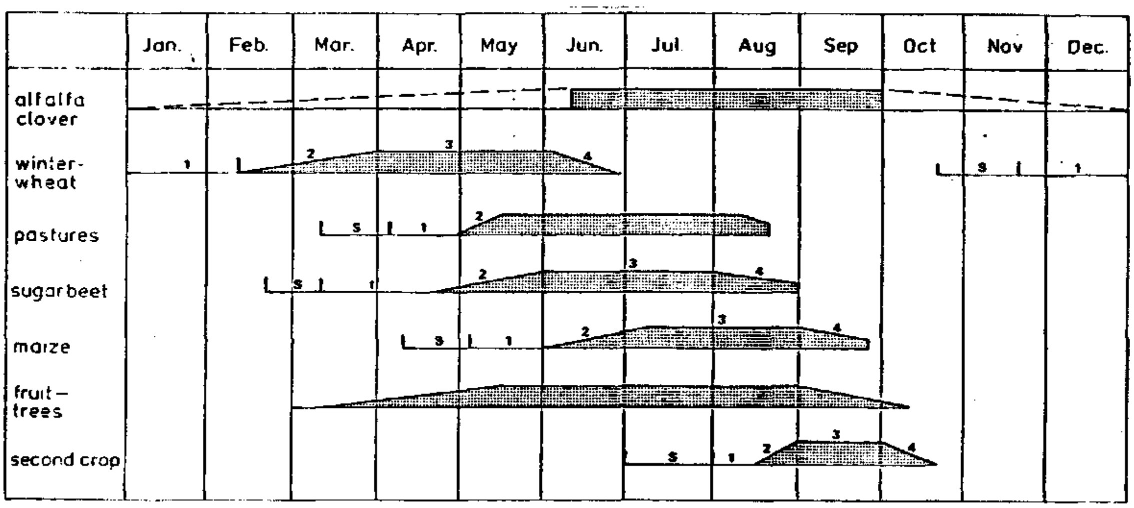

Fig. 2. Crop calendar for main crops, grown in Grande Bonifica Ferrarese and Navarolo

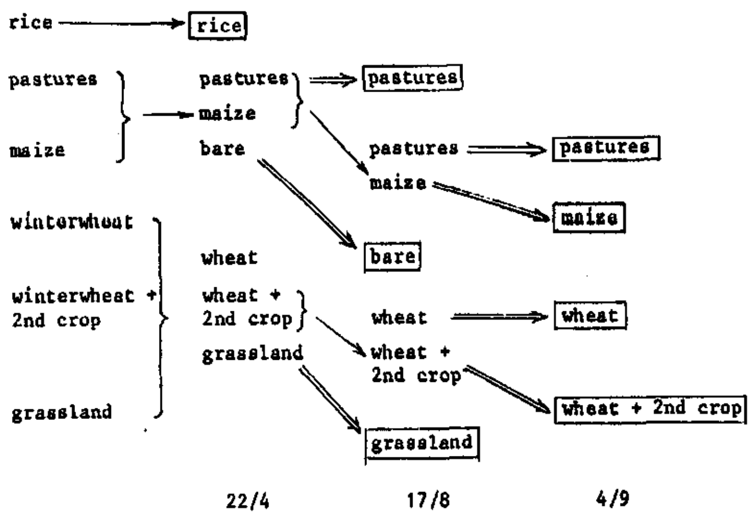

Fig. 3. Discrimination scheme applying to the crops being present in the East Sesia - Villoresi area and to the available LANDSAT-images, as based on TVI

Fig. 3 (after CLERMONT and MENENTI, 1984) shows the six most representative crops of the East Sesia - Villoresi area. Dates, as given in Fig. 3 are those referring to the available LANDSAT-images. By framing a particular crop name, it is meant that a crop can be discriminated on that particular date.

As Fig. 3 shows, the crops can be discerned by means of a multitemporal TVI analysis. The last image, however, plays a too important role: four crops namely pasture, corn, wheat and wheat + 2nd crop, can only be discriminated by means of this image.

Fig. 4 shows the TVI-discrimination scheme applying to seven most important crops of Grande Bonifica Ferrarese - Navarolo.

Although these analyses are rather useful in order to map individual crops, one has to wait until the end of the growing season. In order to detect crop water stress during the irrigation season, crops have to be already mapped in the earlier months of the growing season. The occurrence of plant water stress is disclosed by the actual value of a vegetation index being lower than the normal value, i.e. applying to a healthy crop. It is, therefore, understood that water stress detection is feasible only after a first crop-mapping step, which gives the reference vegetation index value (known for each crop) for each site and date.

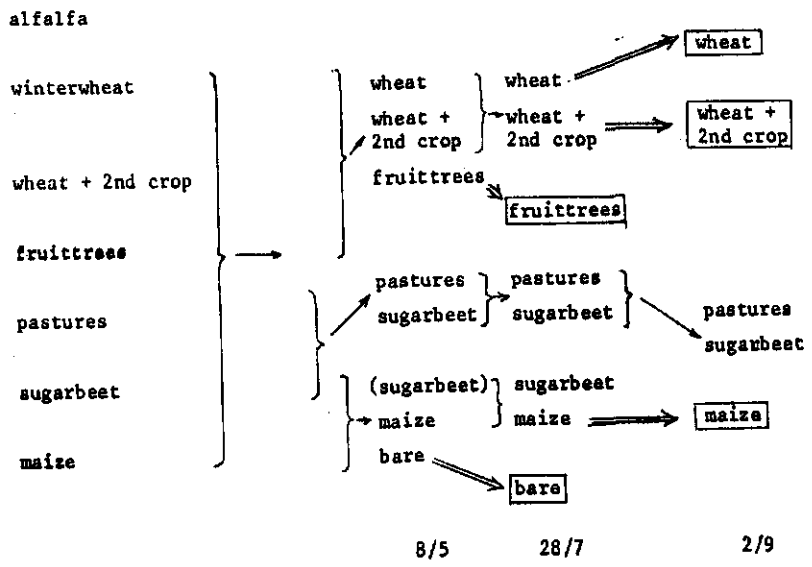

Fig. 4. Discrimination scheme applying to the crops being present in the Grande Bonifica Ferrarese - Navarolo area and to the available LANDSAT-images, as based on TVI

In this case instead of considering a multitemporal analysis of one vegetation index to discriminate each crop as it was proposed by CLERMONT and MENENTI (1984), a multitemporal-multiindex analysis will be attempted. It will be shown that such approach provides some opportunities for completion of the crop-mapping stage, earlier in the growing season than it is the case by applying a multitemporal single-index approach.

5. COMPUTATION OF CONFUSION MATRICES OF VEGETATION INDICES VALUES

A series of confusion matrices regarding greenness, brightness and TVI vegetation indices have been worked out for a number of crops and for different periods of the year. The reference crops present in the confusion matrices are the main crops being present in the study areas, as crop calendars in Figs. 1 and 2 show, with the addition of spring wheat. 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 peculiar for each crop in each month +10% respectively -10% of this value.

The monthly characteristic interval for each reference crop was compared with the corresponding vegetation index value of the other crops in order to detect which one would be a confusion crop for that particular reference crop.

6. RANGE OF VARIATION OF VEGETATION INDICES VALUES FOR EACH REFERENCE CROP

Tables 4, 5 and 6 show the monthly value of each considered vegetation index. They also show when a reference crop is more easily discriminated and which are the confusion crops for a specific reference crop. The multitemporal combined use of different vegetation indices could improve crop discrimination in comparison with the use of only one vegetation index. By comparing Tables 4, 5 and 6, it can be understood that greenness and TVI vegetation indices fare better than the brightness vegetation index in discriminating crops.

For this reason greenness and TVI vegetation indices are the main indices upon which the crop-discrimination technique to be developed will rely. However, brightness vegetation index can be used as third choice on behalf of a multitemporal combined use of three vegetation indices.

Table 4. Confusion matrix, as obtained on the basis of the characteristic greenness value and range of each reference crop. The lower bound (L.B.) and upper bound (U.B.) give the characteristic greenness range for each reference crop. The elements of the confusion matrix are the greenness values of crops, given when either the greenness value or range of these crops fall within the characteristic range of the reference crop; overbars indicate mean values

Reference crop	Characteristic greenness value	L.B.	U.B.	Crop data sets																		
				$\bar{A}$	P_1	L_1	Q_1	S_1	T_1	R_1	C_1	$\bar{O}$	$\hat{a}_1$	D_1	E_1	a_2	m_1	$\bar{N}$	M_1	$\bar{I}$	Z_1	W_1
APRIL																						
$\bar{A}$ spring wheat	0.8	-1.8	1.8											1.2								
D_1 haygrass	1.2	0.2	2.2	0.5																		
$\underline{E}_1$ alfalfa	-6.7	-7.7	-5.7																	-5		
$\bar{N}$ corn	4.2	3.2	5.2		4.3							4.9										
$\underline{C}_1$ pasture	3	2	4		4.3									1.2								
$\bar{I}$ sugar beet	-5	-6	-4			-5	-4.8	-4.5	-4.8													
P_1 trees	4.3	3.3	5.3								3	4.9						4.2				
MAY																						
$\bar{A}$ spring wheat	17.3	15.6	19		19.5									14.3								
D_1 haygrass	14.3	12.9	15.7	17.3							13				12.9							
$\underline{E}_1$ alfalfa	12.9	11.6	14.2										12.7	14.3								
$\bar{N}$ corn	6.2	5.2	7.2									5.9										
$\underline{C}_1$ pasture	13	11.7	14.3											14.3	12.9							
$\bar{I}$ sugar beet	-3.5	-4.5	-2.5			-4			-3.6													
P_1 trees	19.5	17.5	21.5	17.3																		
JUNE																						
$\bar{A}$ spring wheat	28.1	25.3	30.9		27.6		30			26.2												
D_1 haygrass	20.5	18.4	22.6								18.5				21	22		21.6				
$\underline{E}_1$ alfalfa	21	18.9	23.1										22.7	20.5		22	22.8	21.6				
$\bar{N}$ corn	21.6	19.4	23.8										22.7	20.5	21	22						
$\underline{C}_1$ pasture	18.5	16.6	20.4											20.5								
$\bar{I}$ sugar beet	3.5	2.5	4.5																			
P_1 trees	27.6	25	30.6				30															
JULY																						
$\bar{A}$ spring wheat	15.6	14	17.2											18.6								
D_1 haygrass	18.6	16.7	20.5	15.6				20.5			21											
$\underline{E}_1$ alfalfa	11.9	10.7	13.1																			
$\bar{N}$ corn	31.3	28.2	34.4						31.7											29.6	33.2	
$\underline{C}_1$ pasture	21	19.9	23.1		25.5			20.5						18.6			23.1					
$\bar{I}$ sugar beet	29.6	26.6	32.6		25.5													31.3				
P_1 trees	25.5	22.9	28.1							24.8									24.2	29.6		
AUGUST																						
$\bar{A}$ spring wheat	4.4	3.4	5.4			4					5.7			5.2								
D_1 haygrass	5.2	4.2	6.2	4.4							5.7											
$\underline{E}_1$ alfalfa	9.5	8.5	10.5																			9.7
$\bar{N}$ corn	47.6	42.8	52.4																			
$\underline{C}_1$ pasture	5.7	4.7	6.7	4.4										5.2								
$\bar{I}$ sugar beet	30.9	27.8	34																			
P_1 trees	13.6	12.2	15																			
SEPTEMBER																						
$\bar{N}$ corn	24.6	22.1	27.1									25.4								26.5		
$\bar{I}$ sugar beet	26.5	23.8	29.2									25.4						24.6				

Table 5. Confusion matrix, as obtained on the basis of the characteristic brightness value and range of each reference crop. The lower bound (L.B.) and upper bound (U.B.) give the characteristic brightness range for each reference crop. The elements of the confusion matrix are the brightness values of crops, given when either the brightness value or the range of these crops fall within the characteristic range of the reference crop; overbars indicate mean values

Reference crop	Characteristic brightness value	L.B.	U.B.	Crop data sets																				
				$\bar{B}$	E_1	O_1	$\bar{Q}$	T_1	M_1	m_1	P_1	R_1	$\bar{A}$	$\bar{I}$	a_1	a_2	$\bar{N}$	$\bar{D}$	S_1	$\bar{C}$	O_2	U_1	V_1	L_1
APRIL																								
$\bar{A}$ spring wheat	33.4	30.1	36.7											36.5			35							35.
$\bar{D}$ haygrass	57.9	52.1	63.7								53.6	62.1								66				
$\bar{E}_1$ alfalfa	41	36.9	45.1				39.1	36						36.5			35							
$\bar{N}$ corn	35	31.5	38.5		41								33.4	36.5										35.
$\bar{C}$ pasture	66	59.4	72.6									62.1			66.3	67		57.9						
$\bar{I}$ sugar beet	36.5	32.8	40.2		41	40	39.1	39					33.4				35							35.
P_1 trees	53.6	48.2	59	50.9														57.9	51.9					
MAY																								
$\bar{A}$ spring wheat	48.2	43.4	53					44.1						47			42.3							50.
$\bar{D}$ haygrass	61.8	55.6	68	62.3	59.5		63.5				62.1	65.5			61.9	65				61.9				
$\bar{E}_1$ alfalfa	59.5	53.5	65.5	62.3			63.5				62.1				61.9	65		61.8	53.8	61.9				
$\bar{N}$ corn	42.3	38.1	46.5			43		44.1					48.2	47										
$\bar{C}$ pasture	61.9	55.7	68.1	62.3	59.5		63.5				62.1	65.5			61.9	65		61.8						
$\bar{I}$ sugar beet	47	42.3	51.7			43		44.1					48.2				42.3							50.
P_1 trees	62.1	55.9	68.3	62.3	59.5		63.5					65.5			61.9	65		61.8		61.9				
JUNE																								
$\bar{A}$ spring wheat	55.1	49.6	60.6		64.3		57.7				65			53.5				62.8	53.3	60				53.
$\bar{D}$ haygrass	62.8	56.5	69.1	64.4	64.3		57.7				65	63.8		53.5						60				
$\bar{E}_1$ alfalfa	64.3	57.9	70.7	64.4							65	63.8		53.5				62.8		60				
$\bar{N}$ corn	45	40.5	49.5					48.1	42.7	42.7				53.5							42.9			
$\bar{C}$ pasture	60	54	66	64.4	64.3		57.7				65	63.8	55.1	53.5				62.8		60				
$\bar{I}$ sugar beet	53.5	48.1	58.9		64.3	48.5		48.1			65		55.1				45	62.8	53.3					53.
P_1 trees	65	58.5	71.5	64.4	64.3							63.8		53.5				62.8		60				
JULY																								
$\bar{A}$ spring wheat	44.4	40	48.8		52.1				45.4	41.7				50.8			46.6				41.9	48.2	47.7	
$\bar{D}$ haygrass	63.5	57.1	69.9	63.5	52.1	59.3		69.5			63.8	69							64	55.4				
$\bar{E}_1$ alfalfa	52.1	46.9	57.3				52.5				63.8			50.8				63.5		55.4		48.2	47.7	
$\bar{N}$ corn	46.6	41.9	51.3		52.1				45.4				44.4	50.8						55.4		48.2	47.7	
$\bar{C}$ pasture	55.4	49.8	61		52.1	59.3	52.5				63.8			50.8			46.6	63.5						
$\bar{I}$ sugar beet	50.8	44.9	55.9		52.1		52.5						44.4							55.9				
P_1 trees	63.8	57.4	70.2	63.5		59.3		69.5				69		50.8						55.9				
AUGUST																								
$\bar{A}$ spring wheat	41.2	37.1	45.3		45.5							44.3		47.5			48.3						40.4	
$\bar{D}$ haygrass	51.6	46.4	56.8	50.1	45.5						62.9			47.5			48.3		55.7	53.6				
$\bar{E}_1$ alfalfa	45.5	40.9	50.1	50.1								44.3	41.2	47.5			48.3	51.6		53.6				
$\bar{N}$ corn	48.3	43.5	53.1	50.1	45.5							44.3	41.2	47.5				51.6		53.6				
$\bar{C}$ pasture	53.6	48.2	59	50.1	45.5			58.6			62.9			47.5			48.3	51.6	55.7					
$\bar{I}$ sugar beet	47.5	42.8	52.3	50.1	45.5							44.3	41.2				48.3	51.6		53.6				
P_1 trees	62.9	56.6	69.2					58.6										51.6		53.6				
SEPTEMBER																								
$\bar{D}$ haygrass	49	44.1	53.9																					
$\bar{C}$ pasture	61	54.9	67.1						56.3								60.5							
$\bar{N}$ corn	60.5	54.4	66.6						56.3											61				
$\bar{I}$ sugar beet	27.1	24.4	29.8	27																				

Table 6. Confusion matrix, as obtained on the basis of the characteristic TVI value and range of each reference crop. The lower bound (L.B.) and upper bound (U.B.) give the characteristic TVI range for each reference crop. The elements of the confusion matrix are the TVI values of crops, given when either the TVI value or range of these crops fall within the characteristic range of the reference crop; overbars indicate mean values

	Reference crop	Characteristic TVI-value	L.B.	U.B.	Crop data sets																
					A_1	$\bar{a}$	a_5	$\hat{a}_2$	$\bar{X}$	$\bar{C}$	$\bar{E}$	m_1	M_1	$\bar{N}$	$\bar{O}$	$\bar{I}$	U_1	V_1	P_2	L_1	$\bar{D}$
APRIL																					
A_1	spring wheat	0.89	0.84	0.94			0.89			0.95											
$\bar{C}$	pasture	0.95	0.90	1.00	0.89		0.89														0.90
$\bar{N}$	corn																				
$\bar{I}$	sugar beet																				
$\bar{E}$	alfalfa																				
P_2	trees																				
$\bar{D}$	haygrass	0.90	0.88	0.93	0.89		0.89			0.95											
MAY																					
A_1	spring wheat	1.07	1.02	1.12		1.08		1.02			1										
$\bar{C}$	pasture	0.98	0.93	1.03			0.94	1.02			1										0.95
$\bar{N}$	corn	0.85	0.81	0.89															0.91		
$\bar{I}$	sugar beet	0.77	0.72	0.81																	
$\bar{E}$	alfalfa	1	0.95	1.05	1.07			1.02		0.98									0.91		0.95
P_2	trees	0.91	0.86	0.96						0.98	1			0.85							0.95
$\bar{D}$	haygrass	0.95	0.90	1.00			0.94			0.98	1								0.91		
JUNE																					
A_1	spring wheat	1.15	1.10	1.20										1.06		1.11					
$\bar{C}$	pasture	0.95	0.90	1.00					0.98		0.85										
$\bar{N}$	corn	1.06	1.01	1.11	1.15	1.03				1.01		1.06	1.06			1.11					1.13
$\bar{I}$	sugar beet	1.11	1.06	1.16	1.15							1.06	1.06	1.06							1.13
$\bar{E}$	alfalfa	0.85	0.80	0.90				0.85											0.89		
P_2	trees	0.89	0.84	0.94				0.85			0.85										
$\bar{D}$	haygrass	1.13	1.08	1.18										1.06		1.11					
JULY																					
A_1	spring wheat	1.14	1.09	1.19					1.07		1.09			1.10		1.16	1.16			1.17	1.12
$\bar{C}$	pasture	0.96	0.91	1.01															0.92		
$\bar{N}$	corn	1.10	1.05	1.15	1.14				1.07	1.02	1.09				1.07	1.16	1.16				1.12
$\bar{I}$	sugar beet	1.16	1.11	1.21	1.14						1.09						1.16			1.17	1.12
$\bar{E}$	alfalfa	1.09	1.04	1.14	1.14				1.07							1.16	1.16				
P_2	trees	0.92	0.87	0.97															0.92		
$\bar{D}$	haygrass	1.12	1.07	1.17	1.14				1.07		1.09			1.10		1.16	1.16			1.17	
AUGUST																					
$\bar{C}$	pasture	0.97	0.93	1.03																	1.02
$\bar{N}$	corn	1.17	1.12	1.22					1.15							1.17					
$\bar{I}$	sugar beet	1.17	1.12	1.22					1.15					1.17							
$\bar{D}$	haygrass	1.02	0.97	1.07						0.97											
SEPTEMBER																					
$\bar{N}$	corn	1.02	0.97	1.07					1.03									1.06			
$\bar{I}$	sugar beet	1.21	1.16	1.26																	
$\bar{D}$	haygrass	0.85	0.8	0.9																	

7. OPTIMAL LANDSAT-IMAGES FOR CROP DETECTION

After establishing an approach to discriminate crops by means of multitemporal use of vegetation indices, next challenge is to find out how many LANDSAT-images and on which dates are sufficient to discriminate the required crops.

Fig. 5 shows a crop discrimination scheme by applying greenness and TVI vegetation indices. By framing a particular crop, it is meant that it can be discriminated from the other crops by means of an image acquired in that particular month.

It turns out that, for example, winter wheat can be discriminated by the other crops either in April by the use of greenness and TVI or in May by means of the TVI. The combined use of the two vegetation indeces, as the following example shows, is more interesting. Taking the image of June, trees + oats is discriminated from the other crops by the use of greenness; also sugar beet by the same vegetation index is discriminated. If we consider that oats do not appear as main crop in the study areas crop calendars, we could also assume that tree can be also clearly discriminated without having any confusion crop in the month of June. If trees are mapped by means of the June image of greenness, then corn can be discriminated in May by means of TVI; note that in May trees would be a confusion crop for corn. In June, even spring wheat can be discriminated by means of TVI, having previously discriminated its peculiar confusion crops, i.e. sugar beet and corn by means of greenness.

Moreover discriminating spring wheat in June by the use of TVI, it will be possible to discriminate haygrass from spring wheat in April by the use of greenness. By the same method, then, pasture can be separated from haygrass. Four images (April, May, June and July) would give a level of discrimination within crops more than sufficient. However, crops as spring wheat, small grains and oats are not present in the study areas. It is, accordingly, feasible to perform the first crop-mapping step by considering three images only.

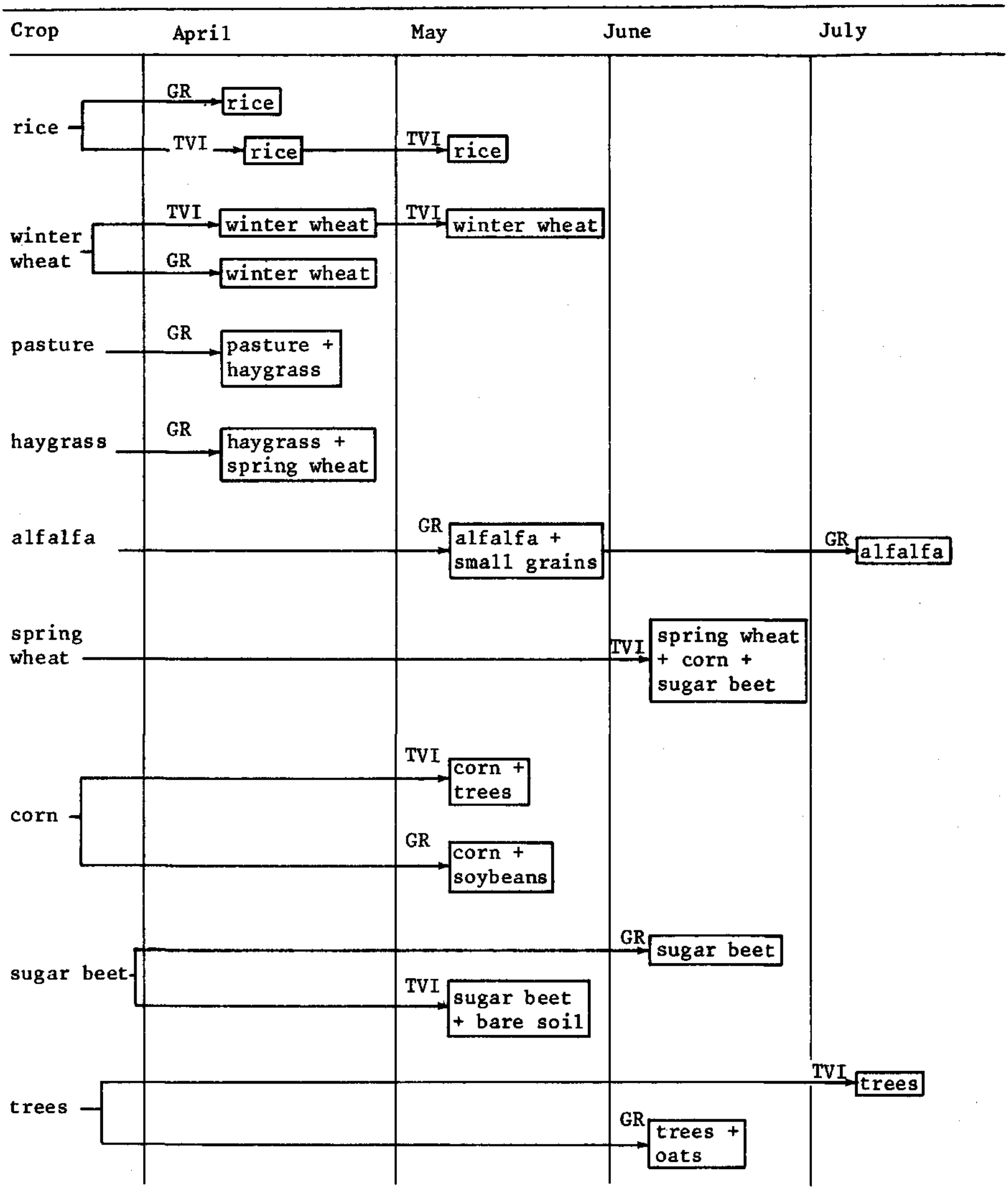

Fig. 5. Crop discrimination scheme by means of the combined use of greenness and TVI, as calculated from LANDSAT-MSS images on different dates

8. ACTUALLY AVAILABLE LANDSAT IMAGES AND RELATED DIFFICULTIES WITH CROP DISCRIMINATION IN THE STUDY AREA

The analysis, as given in the previous section did show in which periods of the year LANDSAT images were more useful for crop discrimination. However, such decision has to cope within the actual availability of LANDSAT images during a considered year and for a particular area.

To illustrate this point Table 7 was prepared. This table gives the number of available and suitable LANDSAT images compared with the theoretically acquired images for six frame numbers during three periods of the year (months of April, May and June) in the years 1980 through 1982. The six frame numbers are: 206.29, 207.29, 209.28, 209.29, 208.28, 208.29 referring to the Po valley, North Italy. The theoretically available images correspond with the date of each satellite overpass. By actually available images it is meant here an image actually stored in the EARTHNET archive. Finally, the suitable images are those where cloud cover is 0 in relevant quadrants, i.e. those quadrants covering a particular study area.

Table 7. Number of available and suitable images, compared with theoretically possible number, for six frame numbers, within the best periods for each test area in 1980, 1981 and 1982. Period a = April, period b = May, period c = June

Year	Theoretically possible number in period			Available images in period			Suitable images in period		
	a	b	c	a	b	c	a	b	c
1980 total	22	20	19	12	12	7	3	2	5
1981	18	20	20	8	6	6	2	3	4
1982	23	18	20	11	6	12	5	6	10

	Theoretically possible total number	Available images		Suitable images	
		number	% of total	number	% of total
1980	61	41	67.2	10	16.4
1981	58	20	34.5	9	15.5
1982	61	29	47.5	21	34.4

It turned out that the year 1981 was the worst year for image suitability concerning the three periods, while 1982 was the best year.

In Table 7 the ratio between the available and suitable images over the theoretically ones is given as relating to LANDSAT 2 and 3, and the period 1980 through 1982. The results in Tables 7 and 8 show that to establish which method performs better, one should take into account the actual distribution of suitable images. Let us compare Table 7 with Table 8. Table 8 was given by CLERMONT and MENENTI (1984), as applying to the same six frame numbers and the same years as Table 7 but considering four different periods along the year. The time periods were selected in both cases on the basis of the methods (vegetation indices) used. The selected time periods shown in Table 8 are the best ones to map crops by means of TVI, while in Table 7 the time periods have been established on behalf of greenness and brightness analysis. In the years 1980 and 1981 the efficiency of the TVI-method to separate crops was higher than of the greenness and brightness method, as shown by a higher frequency of suitable images. In 1982, however, the opposite holds true.

Unfortunately, to chose the required LANDSAT-images one has to cope with the less than optimal availability of such images in the study areas, which plays a main role for such kind of investigation. In fact, eventhough the months during which the best crop discrimination is possible are April, May and June, it was necessary to pick up less than optimal images.

In the next section the multi-temporal multi-index method will be tested in the study-areas to verify the discrimination between crops and to estimate the area actually covered by each crop. Moreover, the actual weather conditions throughout the early growing season in 1980 will be taken into account and the crop calendar given in Fig. 6 accordingly modified.

Table 8. Number of avaiable and suitable images, compared with theoretically possible number, for six frame numbers, within the best periods for each test area in 1980, 1981 and 1982. Period a: East Sesia from 20 April to 10 May, period b: Bonifica Ferrarese from 15 May to 30 May, period c: East Sesia + Bonifica Ferrarese from 20 July to 15 August, period d: East Sesia + Bonifica Ferrarese from 1 to 10 September (after CLERMONT and MENENTI, 1984)

Year		Theoretically possible				Available images				Suitable images			
		a	b	c	d	a	b	c	d	a	b	c	d
1980	L_2	3	3	8	6	–	–	8	6	–	–	4	5
	L_3	6	3	10	1	6	3	10	–	1	1	2	–
	total	9	6	18	7	6	3	18	6	1	1	6	5
1981	L_2	3	2	12	–	3	1	11	–	–	1	6	–
	L_3	3	3	6	6	–	–	5	–	–	–	4	–
	total	6	5	18	6	3	1	16	0	0	1	10	0
1982	L_2	6	3	8	2	–	–	–	–	–	–	–	–
	L_3	3	3	10	5	3	3	8	5	1	3	–	–
	total	9	6	18	7	3	3	8	5	1	3	0	0

	Theoretically possible total number	Available number		Suitable images	
		total	%	total	%
1980	40	33	82.5	13	32.5
1981	35	20	57.1	11	31.4
1982	40	22	55.0	4	10.0

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

9.1. A modified crop calendar applying to the 1980 growing season in the Po valley

Before starting to analyse the multi-temporal multi-index method applied to crop discrimination in the two study-areas, some remarks have to be added about the agricultural consequences of the weather conditions during the 1980 growing season in the Po valley.

In the Po valley, the year 1980 was characterized by a warm winter that suggested to farmers an early seeding of spring crops as sugarbeet and corn. The persistent rain during the months of May and June and the low temperature during the same months, however, did hamper the development of the spring crops. The winter wheat harvest was delayed until mid July, thus affecting the time of seeding of the summer crops. Although the months of May and June were not extremely favorable for the spring crops, they recovered quite well giving a very good yield late in September.

Because of the change in the canopy development, due to the actual weather conditions of 1980, the crop calendar shown in Fig. 2, which was meant to apply to the average year, had to be modified.

Such change in the crop development is described in Fig. 6, that shows the modified crop calendar for the year 1980, as applying to the

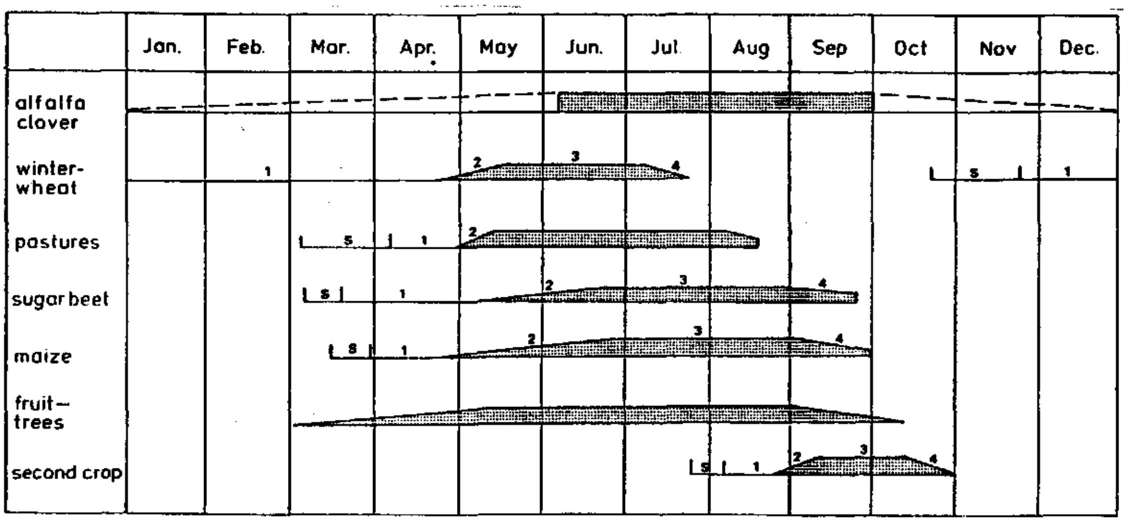

Fig. 6. Modified crop calendar for the year 1980 - Grande Bonifica Ferrarese and Navarolo; s-1-2-3-4: growth stages according to FAO (1979)

irrigation districts Grande Bonifica Ferrarese and Navarolo, in which districts spring and summer crops cover a large surface. As regards the East Sesia irrigation district, such crop calendar modification has not been considered, because spring and summer crops are less important.

9.2. The multi-temporal multi-index analysis applied to the irrigation district Grande Bonifica Ferrarese

By applying the multi-index method, as it was illustrated by an example in Chapter 7, a satisfactory discrimination between crops was reached by considering three images in 1980 of Grande Bonifica Ferrarese as it is shown in Fig. 7. The main crops there present are those given by the crop calendar in Fig. 6.

To evaluate the estimates of the cultivated area by means of the multi-index method, we need a term of reference which should represent

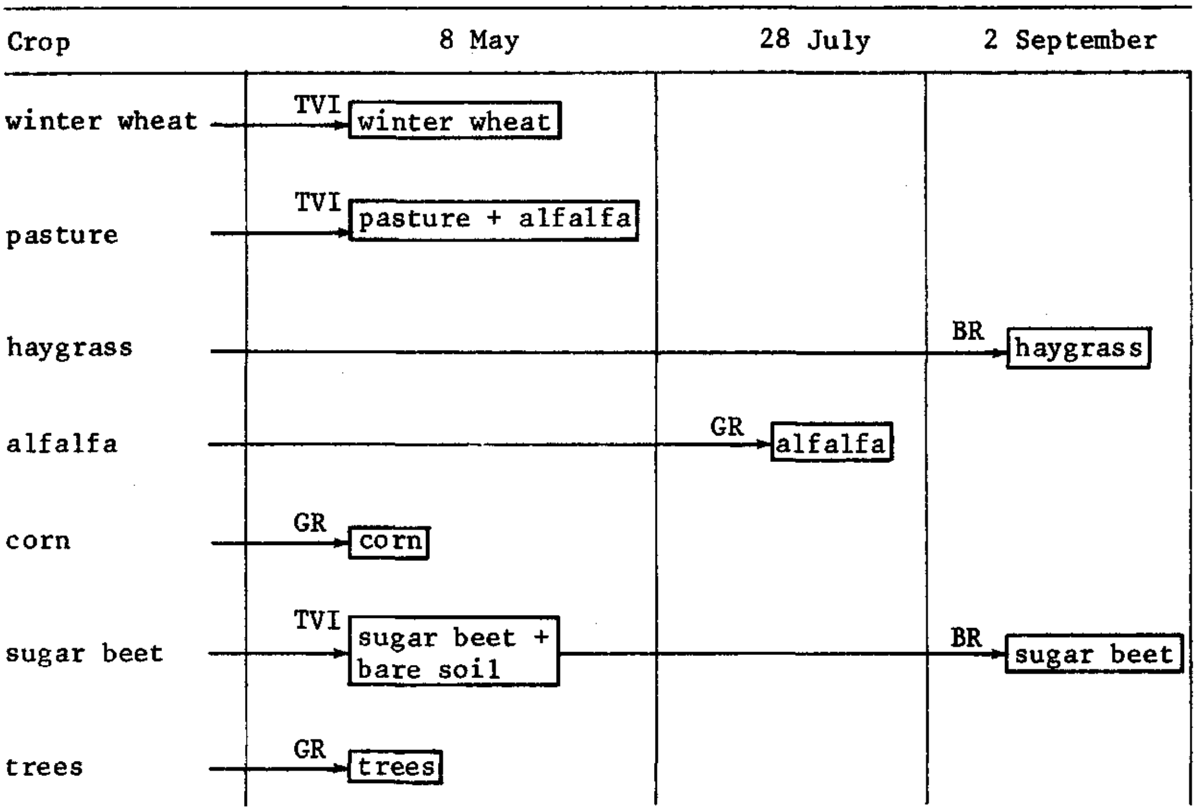

Fig. 7. Grande Bonifica Ferrarese, image 207.29. Available dates: 8 May, 28 July and 2 September. Crop discrimination by the use of three vegetation indices

the actual cultivated area for each crop (hereafter termed 'crop cultivated area'). The procedure to obtain these reference data has been described in detail in NIER-CER (1984); only a summary will be given here.

The cultivated area for each crop and for each irrigation district has been estimated on the basis of statistical data, i.e. the ISTAT-data of the 1981 farming year. These statistical data are lumped figures applying to a particular system of reference (cartographic) units, the so-called 'Zone Agrarie' of ISTAT. These reference units do not coincide with the irrigation districts and they can be either larger of smaller than the irrigation districts. Accordingly, the fraction of each irrigation district (in terms of its territorial area) belonging to each 'Zona Agraria' has been obtained by laying the map of the boundaries of the 'Zone Agrarie' over the map of the boundaries of the irrigation districts. Then these fractions have been applied as weighting coefficients to estimate the cultivated area for each crop within each irrigation district from the statistical data applying to the 'Zone Agrarie'. Table 9 shows the cultivated and irrigated area as percentage of the total territorial area* regarding each main crop in Grande Bonifica Ferrarese. These data represent the term of reference to verify the estimates of the cultivated area as obtained by means of the multi-index method.

Referring to the coefficients of the greenness and brightness formulae utilized in this research as Chapter 2 shows, it has to be pointed out the importance of the variability of the soil reference line for each particular area as one of the main causes of variability of the coefficients of the greenness and brightness formulae. Consequently, by means of greenness and brightness, a new 'soil line' should be computed. To this purpose, the reflectances in the four MSS-bands of the soil types characterizing the study-area must be determined.

The most important soil associations found in the Grande Bonifica Ferrarese irrigation district are two: the alluvial soils group and the organic idromorphic soils group. The latter soils association characterizes

*As territorial area it is meant here the gross area, i.e. including residential area, roads, actual agricultural land, to which the irrigation water authority is responsible for delivery of irrigation water supply

Table 9. Cultivated and irrigated area as percentage of the total territorial area for the 10 main crops cultivated in Grande Bonifica Ferrarese, as estimated on the basis of ISTAT data collected for the 1981 farming year (after NIER-CER, 1984)

Crops	Cultivated area relative to territorial (%)	Irrigated area relative to territorial (%)
Winter wheat	6.5	--
Haygrass	6	1.3
Alfalfa	10	2.2
Pasture	-	-
Corn	11	2.4
Sugarbeet	25	5.4
Trees	14	3
Rice	0.6	0.6
Tomato	2	0.4
Horticultural crops	5	1.1

Table 10. Greenness, brightness and transformed vegetation index values of two characteristic soils located in Grande Bonifica Ferrarese (1 = organic idromorphic soil - Thapto Histic Fluvaquents; 2 = alluvial soil - Dystic Fluventic)

	Bare soil	
	dark[1]	light[2]
GR	3.6	8.9
BR	27.7	41.6
TVI	0.79	0.83

mainly the area of Grande Bonifica Ferrarese as shown by CASALICCHIO et al. (1974).

Values of reflectances in MSS bands 4, 5, 6 and 7 of the two characteristic bare soils were acquired from the May image of Grande Bonifica Ferrarese.

The 'soil line' characteristic of the Grande Bonifica Ferrarese will be computed in a later stage. In Table 10, greenness, brightness and TVI-values of the two characteristic soils are shown in order to establish a reference value for these indices, as they will be applied to discriminate crops from each other.

Table 11 shows the estimated agricultural area for each crop as percentage of the total territorial area. These estimations have been obtained by applying the multi-index discrimination scheme presented in Fig. 7.

Comparing Table 9 with Table 11, the winter wheat area, as estimated by means of TVI is 100% overestimated, while the trees area, as obtained by means of greenness, shows a satisfactory result within 15% underestimation. Still in May, the corn cultivated area as estimated on the basis of greenness is 42% overestimated when compared with the reference value in Table 9.

A remark has to be added regarding the discrimination of sugar beet, which can be separated from the other crops either by means of TVI in May or by means of brightness in September. These two ways to discriminate sugar beet drive to different values of cultivated area (always as a percentage) as it is shown in Table 11: 19.5% of cultivated area by TVI discrimination in May and 39.4% of cultivated area by brightness discrimination in September. Sugar beet was early sown in 1980, as the crop calendar in Fig. 6 shows, so the sugar beet development in May had already reached beyond the stage corresponding to the sugar beet interval of TVI in May. This TVI characteristic interval was estimated on the basis of the average crop calendar (Fig. 2). According to Fig. 2, sugar beet in May is at the emergence stage and the presence of bare soil is still considerable.

So, in Table 11 the September characteristic interval of sugar beet by means of brightness represents a more reliable value to estimate the sugar beet cultivated area, which as percentage was equal to 39.4. Comparing this percentage with that shown in Table 9 for sugar beet, it

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 - Grande Bonifica Ferrarese

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																

appears 60% overestimated. However, because of the meteorological pattern in 1980, sugar beet and summer crops delayed the full maturity stage. That means that the brightness characteristic interval for sugar beet in September has, actually, as confusion crops the summer crops (horticultural crops, tomato and fodder maize) which have not still completed their vegetative cycle. Then, the detected sugar beet cultivated area (39.4%) contains also the summer crops cultivated area.

If we consider, in Table 9, the estimated cultivated area for tomato and for horticultural crops (2% respectively 5%) and also the corn (fodder maize) irrigated area, 2.4%, the total cultivated summer crops area is equal to 9.4%, again as percentage of the territorial area. The total percentage of the cultivated summer crops area (9.4) minus 39.4 will give the cultivated sugar beet area by means of brightness in September. This area is equal to 30% which is still overestimated (20%), as compared with the sugar beet figure in Table 9.

The estimated alfalfa cultivated area (see Table 11) as obtained by means of greenness in July has been overestimated by 22% in comparison with the value in Table 9.

Moreover, again in Table 11, the estimated haygrass cultivated area (by means of brightness in September) shows a 65% underestimation.

9.3. The multi-temporal multi-index analysis applied to the irrigation district East Sesia

By applying the multi-index method, a good discrimination between crops was persued by making use of three images in the 1980 of the East Sesia as it is shown in Fig. 8. The main crops shown in Fig. 8 are those given by the crop calendar in Fig. 1.

In Table 12 the actual cultivated and irrigated area is given as percentage of the total territorial area for each main crop in East Sesia-Villoresi (NIER-CER, 1984). The results in this table will serve as reference terms to evaluate the results to be presented in Table 14. As it was done for the previous irrigation districts (Section 9.2), the most important characteristic soil associations were also considered (IPLA, Torino, 1979). From the April image, the reflectances in MSS-bands 4, 5, 6 and 7 of two characteristic soils were obtained to calculate a new 'soil line' for the study area. Table 13 shows the vegetation indices values for the two most characteristic soils in the East Sesia

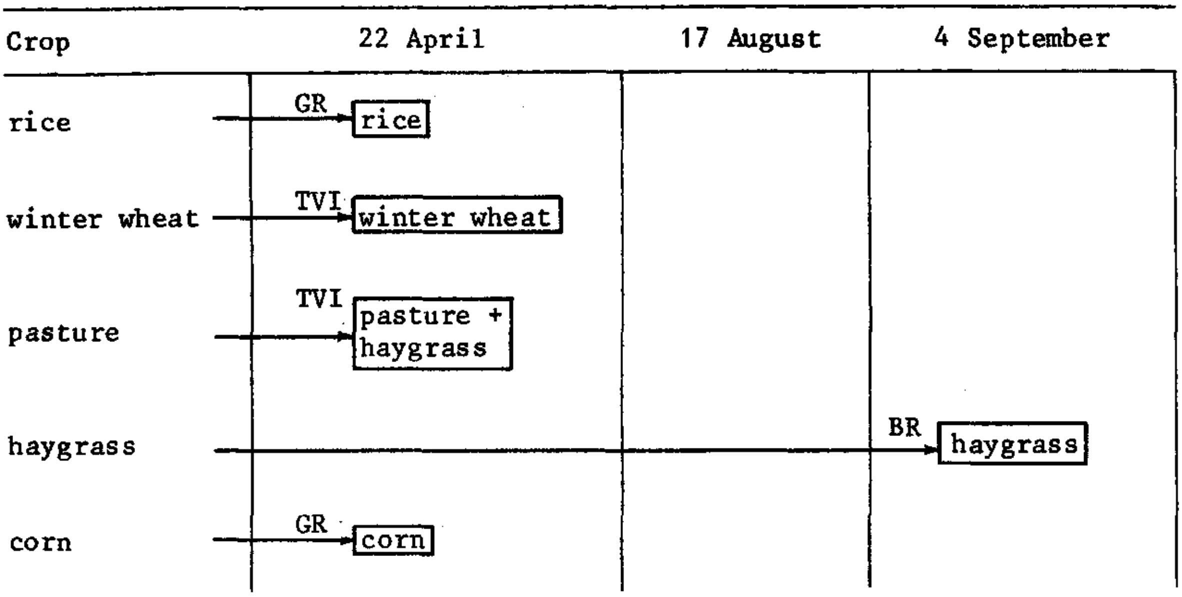

Fig. 8. East Sesia - Villoresi, image 209.29. Available dates: 22 April, 17 August and 4 September 1980. Crop discrimination by the combined use of three vegetation indices

Table 12. Cultivated and irrigated area as percentage of the total territorial area for the five main crops cultivated in East Sesia, as estimated on the basis of ISTAT data collected for the 1981 farming year (after NIER-CER, 1984)

Crops	Cultivated area relative to territorial (%)	Irrigated area relative to territorial (%)
Rice	30	30
Haygrass	29	22
Corn	19	14
Pasture	6	4.5
Winter wheat	4.5	-

Table 13. Greenness, brightness, transformed vegetation index values of two characteristic soils, and of open water in East Sesia (1 = Typic Hapludalfs Chromic Luvisols; 2 = Typic Hapludalfs Gleyc Luvisols)

	Bare soil		Water
	1	2	
GR	5.8	7.2	-5.6
BR	29.6	41.5	20.3
TVI	0.94	0.93	0.66

Table 14. 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 multi-temporal multi-index method - East Sesia

Crops	April						August						September					
	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%	GR	%	BR	%	TVI	%
Rice	(-7,-2)	17.5																
Haygrass					(0.88,0.93)	16.4									(44,53)	14.7		
Corn			(32,39)	23.6														
pasture					(0.90,1.00)	47.6												
winter wheat					(1.07,1.17)	4.9												

irrigation district, and besides them, the vegetation indices values of open water, as needed to classify paddy rice in April. The vegetation indices values for open water were computed on the basis of lake reflectance values in the MSS-bands, as measured by BÜTTNER and VÖRÖS (1981).

Table 14 shows the estimated area for each crop as obtained by applying the multi-index discrimination scheme presented in Fig. 8.

Comparing Table 14 with Table 12, the winter wheat cultivated area in April estimated by means of TVI is 9% overestimated, while the percentage of rice cultivated area in April estimated by means of greenness is 42% underestimated. However, a rather good estimation of rice cultivated area on the multi-temporal colour composite of TVI images was reached by means of visual interpretation* (J. KOOLS and J. KORTLANDT, personal communication, 1985).

Always in April, the corn cultivated area estimated by means of brightness (Table 14) is 24% overestimated compared with that calculated in Table 12. In September the haygrass cultivated area estimated by means of brightness is 43% underestimated.

When the April image is considered, the characteristic TVI interval for pasture shows haygrass as the main confusion crop. It means that the pasture cultivated area (as percentage of the total territorial area) is equal to 47.9 and estimated by means of TVI in April, includes both pasture and haygrass cultivated areas. But, having already calculated the haygrass cultivated area (14.7), the actual percentage of pasture cultivated area will be equal to 32.9 (47.6 - 14.7 = 32.9). Unfortunately, the pasture cultivated area (32.9), as estimated by means of TVI, is much larger than the figure of pasture cultivated area given in Table 12.

*The multi-temporal colour composite image was elaborated starting from the three TVI-images of East Sesia

10. CONCLUSIONS

The multi-temporal multi-index method has been tested out within the two areas object of this study. The method did not always perform in a satisfactory way, giving some remarkable mis-estimations both in Grande Bonifica Ferrarese and in East Sesia. However, an average deviation of ±25% of the crop cultivated areas, as estimated by means of the multi-index method, in comparison with the actual crop cultivated areas (Tables 9 and 12) is a promising result. Then, the crops cultivated areas properly detected were five out of the eleven present in the two irrigation districts.

It should be noted that the inaccuracy in estimating the crop cultivated areas is, at least partly, offset by the capability of the multi-index method applied to LANDSAT-MSS images to yield the crop map of the irrigation districts.

The images showing the topographical details of the study areas, the location and the extent of the crop cultivated areas, and the main soil types provide the cartographic information which is needed to couple properly the calculation of soil water balance to the irrigation network. The latter is the overall goal of the present investigation. It is self-evident that the statistical data in Tables 9 and 12 cannot give this information in map form.

Moreover, the procedure as illustrated in Chapter 9, Section 2, which has been applied to obtain the reference data, is not very accurate (Tables 9 and 12). Furthermore, the crops distribution between the year 1981 (to which the reference data refer) and the year 1980 (to which the results of the multi-temporal multi-index analysis refer) could have been different especially as regards the yearly crops.

According to the previous remarks, the mis-estimates of the crop cultivated areas detected by means of the multi-temporal multi-index method could be partly acceptable results.

In order to verify, furthermore, the reliability of the results given by the multi-index method, a comparison between data in Tables 11 and 14 and new acquired reference data was done. The new acquired reference data are the extent of the agricultural area of each main crop grown in the 1980 farming year and they are expressed, in Tables 15 and 16, as percentage of the agricultural area of the provinces to which the study-irrigation districts belong (ISTAT, 1982).

Few remarks on the nature of these new acquired data should be added. The data regarding the extent of the crop areas in the province of Ferrara apply to the entire province, while the Grande Fonifica Ferrarese occupies 27% of the territorial area of Ferrara province. The latter is characterized by a flat and uniform morphology (100% plain). Because of that we can suppose that the crop distribution will have the same pattern all over the provincial agricultural area.

The East Sesia irrigation district is part of the total territorial area of Novara province. The territory of Novara province is not homogeneous and 65% of its total territorial area is occupied by mountains (uncultivated area) and upland extensive pasture. The rest of the territory is partly occupied by hills (13%) and plain (22%) on which the main crops are grown. Then, instead of calculating the percentage of the crop cultivated area from the whole agricultural area, we referred it mostly to an area in which 90% of the crops was grown. That area (three 'zone agrarie' no. 11, 12, 13) is the 85% of the portion of the entire MSS-frame, which has been studied in detail. It should not be forgotten that we are now able to compare data (Tables 11-15 and Tables 14-16) belonging to the same farming year.

As regards the Grande Fonifica Ferrarese irrigation district, the new reference data shown in Table 15, are rather different from the ones in Table 9.

The comparison between Table 15 and 11 suggests the following remarks:

- winter wheat cultivated area detected by means of TVI in May is 46% overestimated;
- corn cultivated area detected by means of greenness in May is 95% overestimated;
- trees cultivated area detected by means of greenness in May is exactly estimated;
- sugar beet cultivated area detected by means of TVI in May is 2.5% underestimated;
- alfalfa respectively haygrass cultivated areas detected by means of greenness in July respectively by means of brightness in September were underestimated by 2%.

Then in the Grande Bonifica Ferrarese four out of six crops were

Table 15. 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 16. 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	9
corn	24.3
pasture	46.7
winter wheat	6

properly detected by means of the multi-temporal multi-index method.

Regarding the irrigation district East Sesia, the new reference data shown in Table 16 are rather different from those in Table 12, especially about pasture and haygrass.

Comparing results shown in Tables 16 and 14, we are able to remark that:

- rice cultivated area estimated by means of greenness in May is 46% underestimated, while by means of multi-temporal TVI analysis 20% was underestimated;
- corn cultivated area obtained by means of brightness in May is 2.9% underestimated;
- haygrass cultivated area obtained by means of brightness in September is 63% overestimated;
- pasture cultivated area obtained by means of TVI in April is 29.6% underestimated;
- without discriminating those two crops and detecting them together, the pasture and haygrass cultivated areas by means of multi-index method was only 14.5% underestimated comparing with the sum of the same areas in Table 16;
- winter wheat cultivated area estimated by means of TVI in April is 18.3% underestimated.

Then, the crops cultivated areas properly detected in the East Sesia by multi-index method were five out of five crops. Considering together the results of the two irrigation districts, the crops properly detected were nine out of the eleven present in the two study areas. This result shows that the multi-temporal multi-index method improved its performance when more reliable reference data were provided.

Moreover, if a few reference test plots were available during the growing season to obtain actual and strictly reliable reference data, the method would provide a better understanding of the capabilities of the applied technique.

Another factor that can improve the performance of the multi-temporal multi-index method is the availability of suitable images at the beginning of the growing season.

In conclusion, even though there is a will to increase the use of LANDSAT-images for many practical applications, the uncertain number of yearly available images, firstly, and, secondly, lackness of reference data in order to tune up the method, inhibit the operational development of this tool. It must be emphasized that the feasibility of mapping individual crops by means of LANDSAT-MSS data is definitely proven in principle. What is needed is a semi-operational use of such data, which would provide for an opportunity to figure out the practical details and the amount of needed ancillary and ground-reference data, given the required accuracy of determination.

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LIST OF CODES

Codes of the crop-data-sets considered in this report

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)