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MATCHING THE ANALYSIS OF LANDSAT DATA TO USERS'S REQUIREMENTS

Progress report of the project: Mapping crops and their probable water stress by means of satellite images for a better irrigation management in two Italian irrigation districts

M.Sc. Dott.ssa S. Azzali

Institute for Land and Water Management Research (ICW),
Wageningen, The Netherlands

instituut voor cultuurtechniek en waterhuishouding, wageningen

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1. INTRODUCTION

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

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

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

The project described in this report is supported by EARTHNET as a pilot project and its purpose is to develop an operational method able to determine quality, quantity and type of crops and to assess probable water stress by means of LANDSAT-images.

The practical aspects of this operational application are being defined in two irrigation districts located in the Po valley, Italy, namely East Sesia and Grande Bonifica Ferrarese (Fig. 1).

2. DESCRIPTION OF THE IRRIGATION PRACTICE IN THE STUDY AREAS

The territorial area of East Sesia irrigation district is 210 000 ha while the Grande Bonifica Ferrarese area is 56 150 ha. In both the irrigation districts irrigation water is allocated on fixed rotational intervals on the basis of the hectarages of the growing crops. Table 1, indeed, shows how the irrigation water charges depend on cultivated crops.

Table 1. Water charges in East Sesia irrigation district in 1982

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

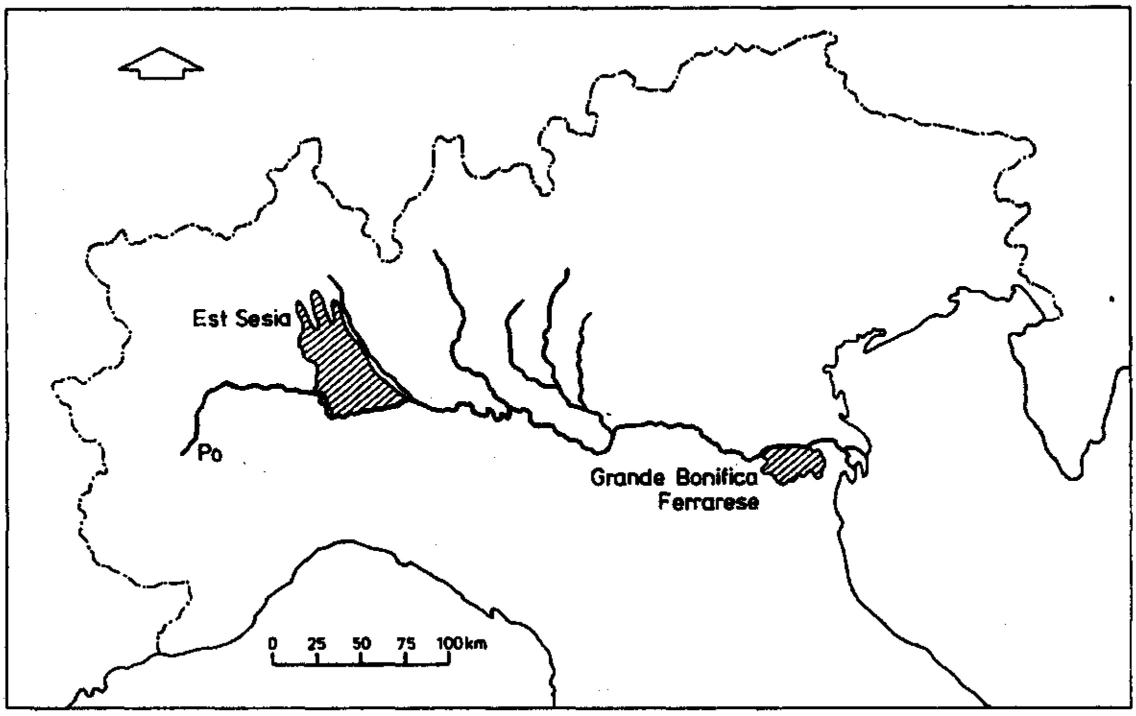

Fig. 1. Sketch map of the Po valley, where the two irrigation districts considered in this report are indicated

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

For example, in the East Sesia during 1981 only the 42% of the allocated water diverted into the entire district was actually applied to fields. Moreover, in the Grande Bonifica Ferrarese during 1981 only the 13% of the allocated irrigation water was utilized (NIER, 1984). Such analysis points out that the water allocation criterion applied by the irrigation districts is the maximum guarantee against the risk of crop water stress between two irrigation turns.

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

An improved allocation of irrigation water could be achieved by means of a satellite based control procedure to provide the exact information on crop types, cultivated area and probable water stress. This would make feasible a more demand-oriented allocation procedure.

The semi-operational test of the multi-temporal multi-index method will help to understand the shortcomings in the irrigation districts. Furthermore, analysing the current irrigation season, an improved irrigation strategy can be set up for the coming season.

3. APPROACH

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 indices presents additional difficulties. Computation of crop water stress by means of spectral measurements has been studied through about a decade. Near infrared and red wavelengths and the irratio, 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.

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 has been evaluated by means of LANDSAT-MSS images in the year 1980. Moreover, the possibility of improving the performance of the various vegetation indices by applying them in a combined manner, has been evaluated, and the results have been presented by AZZALI (1985a,b).

To improve and to evaluate the performance of the multi-temporal multi-index method field data have been collected in 1985. Ground control plots have been located, where the crop being grown is known, to assess the accuracy of the crop maps obtained with the LANDSAT-data. Moreover meteorological data referring to the whole year 1985, as needed to simulate the soil water balance have been collected. Such calculations give the variation of actual evapotranspiration and soil water content through the dry period and can therefore be applied to evaluate the accuracy of crop water stress detection, as obtained from LANDSAT-data.

As regards the analysis of satellite data we are considering:

- Processing and analyses of the new LANDSAT Thematic Mapper (TM) data, which have a 30 m resolution, instead of the LANDSAT Multi Spectral Scanner (MSS) data, which have a 80 m resolution.
- Application of the multi-temporal, multi-index method to the TM-data to map crops and their probable water stress; evaluation of the accuracy on the basis of field data.
- Application of the thermal infrared satellite data, i.e. TM-Band 6 and NOAA/AVHRR Channel 5, to map probable crop water stress; comparison with results of the second step.
- An attempt will be done to identify the areas irrigated by means of groundwater extracted directly by farmers, i.e. those areas where no irrigation network is present and where no crop water stress is detected.

4. ESTABLISHING NEW CROP CALENDARS: DATA COLLECTION AND COMPILATION OF AVERAGE CROP CALENDARS IN 1985

The importance of a reliable crop calendar for the study areas was stressed in the previous reports by AZZALI (1985a,b). It turned out that the knowledge of crop calendar variability within a particular area is the initial information to acquire in order to discriminate the crops from each others by means of LANDSAT-images.

In order to test, in a more accurate way, the results of the multi-temporal multi-index method (AZZALI, 1985a,b) in both the irrigation districts several field plots have been selected and agronomic informations have been recorded on the actual cultivated crops.

In the East Sesia irrigation district 11 reference plots of rice in different farms, 7 plots of corn, 5 of grass-field and only 1 of winter wheat have been chosen. The two latter crops are gradually disappearing from East Sesia. Table 2 shows a list of the ground truth plots located in the East Sesia irrigation district. For each plot a form was filled up, including agronomic informations on crops as dates of occurrence of phenological stages, irrigation management, etc.

The same investigation procedure was repeated in the Grande Bonifica Ferrarese irrigation district. Table 3 shows the list of selected farms and ground truth plots regarding the cultivated crops in that area.

Table 2. Ground truth plots in the East Sesia irrigation district

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

From the collected agronomic informations regarding the main crops an average crop calendar has been established for East Sesia (Fig. 2) respectively Grande Bonifica Ferrarese (Fig. 3). In these crop calendars the phenological stages have been coded and defined as follows:

(-1) seeding stage

(0) emergence

(1) full cover

(1a) interruption winter dormancy (only for winter wheat)

(1a) tillering (only for rice)

(1c) head development

(2) flowering

(3) yield formation

(3) milk ripening (only for grains)

(3a) pod development (only for soybeans)

(4) full ripening

(5) harvest

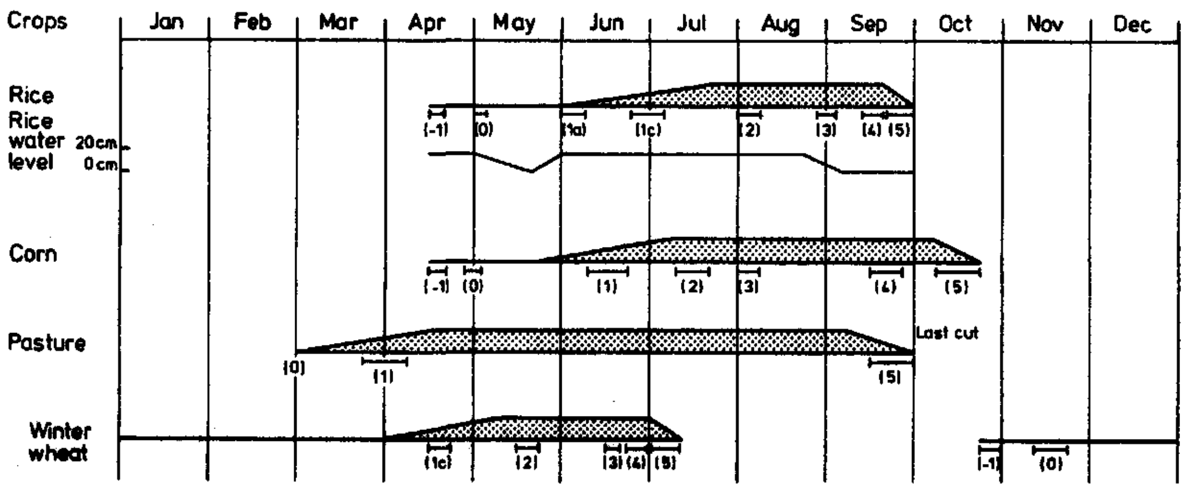

Fig. 2. Average crop calendar for year 1985 in East Sesia; for definitions of phenological stages see text

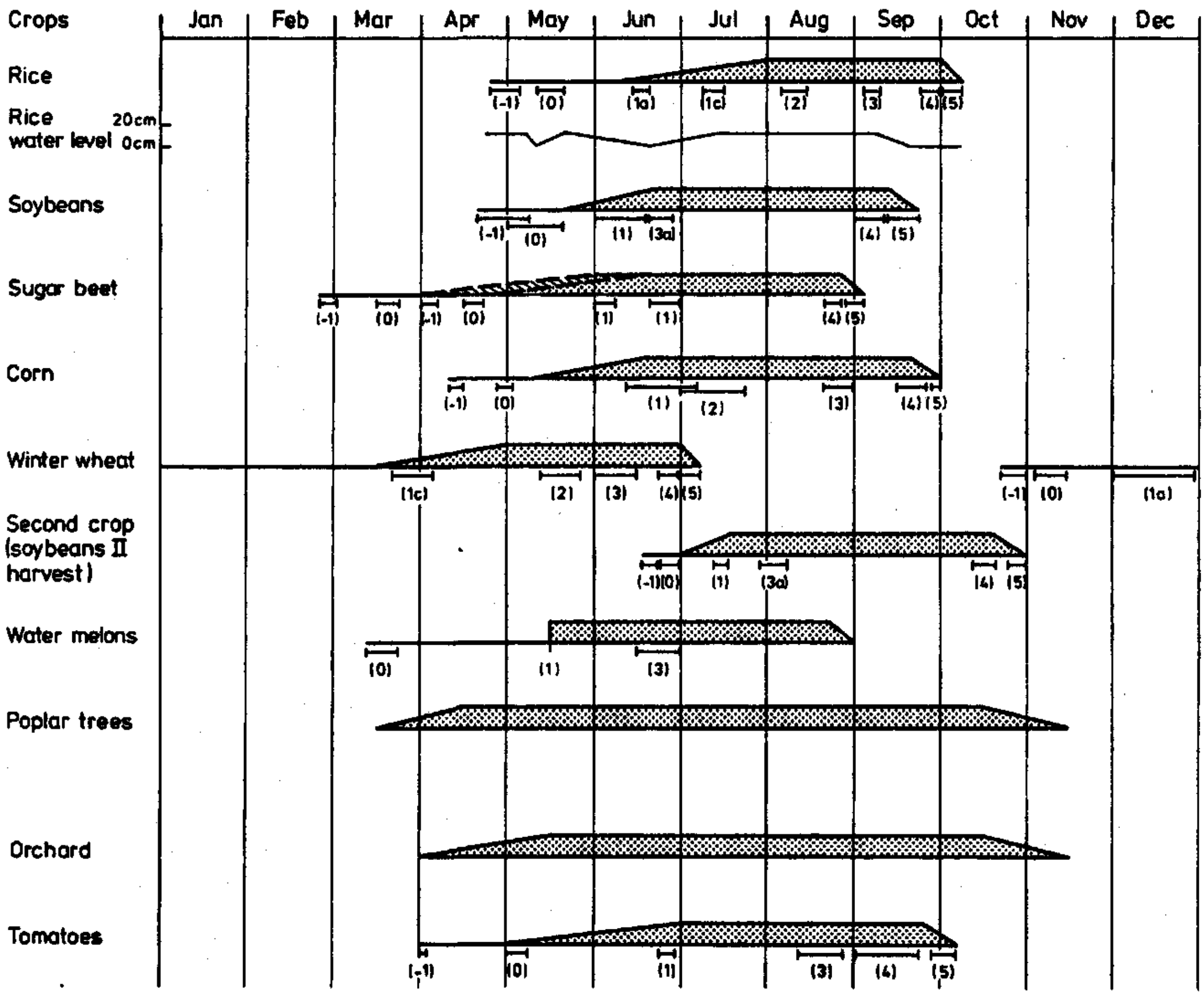

Fig. 3. Average crop calendar for year 1985 in Grande Bonifica Ferrarese; for definitions of phenological stages see text

Table 3. Ground truth plots in the Grande Bonifica Ferrarese irrigation district

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

Concerning the Grande Bonifica Ferrarese irrigation district (crop calendar Fig. 3) we did not include in the list of crops strawberry, sunflower and vineyard, being those crops not important in that area. Furthermore, in Fig. 3 no specific phenological stage is considered for poplar and orchard, so the calendar indicates leaves development, full vegetative cover and leaves loss.

5. FROM METHODOLOGY TO OPERATIONAL APPLICATION: SOME PRACTICAL CONSTRAINTS

5.1. Actually available and suitable LANDSAT images

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

The cloud cover assessment procedure as applied by EARTHNET deserves an additional comment. In Table 5 the cloud cover assessments are compared as given for the same images as received by the Fucino respectively the Kiruna ground stations. The differences are sometimes very large and they have been noted for LANDSAT images of other parts of Europe.

Table 4. Number of available and suitable images, compared with theoretically possible number of satellite overpasses within April till September, for the two study irrigation districts from 1980 through 1985

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

Table 5. Differences of cloud cover assessment between Kiruna and Fucino (EARTHNET groundstations) archives

4	192	29	KI M - 820907	7	8	8	8
4	192	29	FO M - 820907	8	9	8	9
4	192	29	KI M - 830113	8	8	4	4
4	192	29	FO M - 830113	0	1	3	1
4	192	29	KI M - 830622	5	5	9	8
4	192	29	FO M - 830622	3	4	9	8
4	192	29	KI M - 830708	4	5	5	7
4	192	29	FO M - 830708	1	2	2	3
4	192	29	KI M - 830910	8	3	8	7
4	192	29	FO M - 830910	6	2	8	8

Finally a few comments on the order and delivery procedure. The sequence of action was as given below:

15-30 Sept. 1985	field work
30 Sept. - 2 Oct.	list of available images (1/1/85 to 20/8/85)
3 Oct.	quick looks ordered
28 Oct.	quick looks received
28 Oct.	list of available images (20/8/85 to 30/9/85)
7 Nov.	ordered images: 194/28 III and IV quad. 30/4/85 192/29 II quadrant 2/5/85
1 Oct. - 15 Dec.	preliminary analysis of field observations
28 Nov.	approval by EARTHNET - TELESPAZIO of pilot project
19 Dec.	ordered images: 194/28 III and IV quad. 3/7/85 and 20/8/85 192/29 II quadrant 22/8/85
28 Jan. 1986	received images ordered 7 Nov. 1985
26 Febr.	received images ordered 19 Dec. 1985

Although the entire procedure is likely to take less time when working in an operational mode, i.e. out of the pilot-project agreement, it would still take long enough to put an additional constraint on the kind of application being developed. When we look at the 'safe yield' of suitable LANDSAT images (Table 4) and at the time required for the analysis of this data, we can conclude that quasi real time crop monitoring is not feasible, while there is a clear potential for strategic planning of irrigation water allocation.

5.2. Variability of crop phenology due to agricultural practices

Crop mapping by means of LANDSAT data is a relatively well established technique. There is, however, a meaningful difference between what is possible in principle and applications in an operational mode. An issue which deserves particular attention is the relation between the actual phenology of crops in the study area and the average crop calendars shown in Figs. 2 and 3, as actually applied to image analysis.

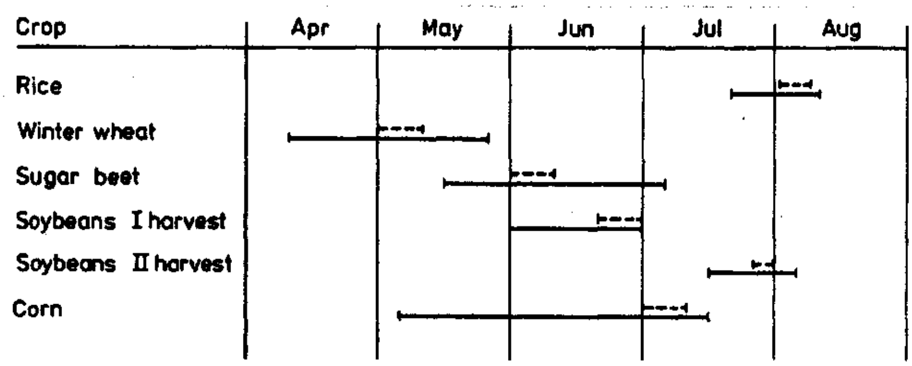

Fig. 4. Attainment of 100% ground cover, Grande Bonifica Ferrarese growing season 1985; continuous line applies to actual phenological observations; dotted line to average crop calendar

In Fig. 4 the periods of attainment of 100% ground cover are compared for the different crops as given by the average crop calendar applying to the Grande Bonifica Ferrarese respectively by the actual phenological observations. It appears that the mean crop calendar would suggest a more clear cut separability of crops than actually is the case.

A consequence of this result is that a pre-operational study would always be needed to adapt the general approach of crop monitoring by LANDSAT to the actual constraints applying to a specific area.

6. DECLARED VERSUS ACTUAL CROP CULTIVATED AREA: A PRACTICAL RESULT

Part of the available TM-images has been already processed in order to map the different crops in the two study areas. Photo 1 shows part of the territory of Grande Bonifica Ferrarese of a colour coded LANDSAT-TM image on 2 May 1985. Winter wheat, green at that time of the year, is indicated by red colour. Paddy rice fields are black-dark blue, while gray-blue colour indicates bare soil and cultivated fields in which soil vegetation cover is lower than 25%. According to the interviews to the farmers done last September, the green framed field in photo 1 was cultivated with winter wheat. Nevertheless, the colour of this field is not red but light gray-blue which denotes that the field is not cultivated with winter wheat but with another crop. Further support to such conclusion is given by a colour coded TM-image (slide 2) of the same area 4 months later (22 August 1985).

In photo 2, the so-called wheat field should appear in dark-blue-blue colour which denoted, at that time, the fields in which was previously grown wheat without a second crop. Nevertheless, the so-called wheat field is red which denotes the presence of a spring-summer crop as it happened to the surrounding fields (soybeans cultivations).

Noting that the irrigation charges of the Grande Bonifica Ferrarese to the farmers are depending on the type of cultivated crops, we should remark that winter wheat belongs to the category of not-irrigated crops while soybeans to the irrigated ones. So, that farm has cultivated in the year 1985 more hectares with irrigated crops than declared to the irrigation district, with the consequence of paying less than due.

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

Photo 3 shows a colour coded TM-image of part of the territory of East Sesia irrigation district on 30 April 1985. Full covering vegetation, that at that time of the year was grassland, is red colour, while the paddy rice fields are denoted by dark blue colour. The corn fields are in light gray-blue colour. Remarkable is the excellent resolution of the TM-image (evidenced also in photo 1 and 2) when compared with the black framed area in photo 4 (colour coded MSS-image of the same area on 22 April 1980). It shows how detailed a TM-image is. This detail is rather essential for the here described application, since the mapped crop cultivated areas must be tied to the irrigation canals.

7. CONCLUSIONS AND RECOMMENDATIONS

- Crop monitoring by LANDSAT involves crop identification in the first part of the growing season and water stress detection in the late growing season.
- Application of different vegetation indices in a combined manner enhances the opportunities for crop identification.
- There are meaningful differences between the general methodology and the way this methodology can be applied to a specific area.
- Pre-operational tests are needed before such applications achieve true operational status.
- The break-even point of irrigated crop monitoring is within easy reach. The here described application would probably cost 20 KAU per year per district when operational. Since the irrigation water charges amount to some 80 $AU \cdot ha^{-1} \cdot year^{-1}$, the identification of only 250 ha of erroneous declarations would pay the cost of the application. Moreover, the irrigation water set free for other uses, e.g. industries, by a better targeted allocation would further enhance the scope of irrigated crop monitoring by LANDSAT.

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