USING NDVI/AVHRR DATA FOR CROP MONITORING AND FORECASTING IN SOUTH ITALY

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ABSTRACT : Crop monitoring, and in particular yield estimate and forecast is considered very important for those Boards in charge to monitor agrarian season. Remote Sensing for its features and potentiality can contribute to these tasks in some new and interesting ways. This study is aimed to investigate the potential use of AVHRR/NDVI data from NOAA satellites for crop monitoring in South Italy within an interregional agrometeorological project. Over 1600 images in LAC format are processed from 1986 to date. Using previous results on NDVI correlation with plant photosynthetic capacity and efficiency during wheat Grain Filling Period Duration (GFPD) a simple linear regression model has been derived for wheat yield estimate and forecast for each South Italy Agricultural Region. Estimated and forecasted values are compared with official ISTAT data .

INTRODUCTION

Since the beginning of the 80', crop monitoring, yield estimate and forecast are research items for scientists involved in Remote Sensing applications. In fact R.S. features and potentiality can contribute to these tasks in some new and interesting ways.

Continued and repeated observations in time, synoptic coverage of the area investigated together with the possibility to observe red and near-infrared plants' radiometric response and photosynthetic efficiency during the whole agricultural season, allow to record crop reactions to environmental stresses and constraints directly and in real time, avoiding to pass through growth simulation models, and to collect a huge and expensive quantity of data.

Because of this potentiality a number of international and national projects have assessed (F.A.O. Agro-ecological Zone Project, EEC M.A.R.S. Project) in order to identify the correct methodology to monitor agriculture dynamic, and in particular the correct instruments and satellites.

The best tool available at the moment for environmental monitoring through remote sensing is represented by AVHRR data from NOAA satellites. High imaging frequency (2 passages a day for each satellite) and relative cheapness but, first of all, the spectral range of Channel 1 and 2 allow to monitor environment day by day.

On the other hand these satellite present a low ground resolution (1 to 4 Km) that particularly in the European average agricultural conditions means very often a mixed pixels observation.

Further research has been developed in order to connect traditional agrometeorological outputs with remote sensing data, even as input information even as calibration support.

This work is aimed to report on the use of NOAA/AVHRR data for crop monitoring in South Italy within the framework of T.E.R.R.A. del SUD Project of the National Agency for South Italy Development (I.A.S.M.).

Project main aims are to assess an interregional Agro-meteorological Service for agriculture monitoring. Within this structure weather forecasting, land-use mapping and idrological monitoring are foreseen.

The Agrometeorological component of the Project is organised to build a crop monitoring system capable of yield forecast and estimation at interregional level.

Project research activity begun in 1991 and will end in the beginning of 1994. After this date, however, operational activities will be continued for a number of years.

METHODOLOGY

The methodology adopted is similar to that followed in a previous work done for wheat on a typical agricultural environment of North Italy in 1988/90: the Emilia Romagna region (Benedetti, Rossini, 1992). However some new methods are introduced in order to improve accuracy in vegetation response measure, data quality and to extend the results obtained to other crops.

Satellite data are used together with official agricultural statistics.

The agricultural seasons considered are those ranging from November 1985 till October 1993. According to Italian crop calendars, each season starts in November and end in October of the following year. In this way 8 agricultural seasons are considered for the historical time series construction.

For the incoming season (November 1993-October 1994) an operational phase of the project it is foreseen with real-time data processing .

Methodology is organised into 3 subsequent steps :

1) NOAA-AVHRR data processing
2) Data stratification and Agricultural Monitoring Areas construction
3) NDVI based yield estimate and forecast

NOAA-AVHRR DATA PROCESSING

For vegetation monitoring is commonly used theNormalised Difference Vegetation Index (NDVI) obtained by a linear combination of Channels 1 and 2 of NOAA/AVHRR data. A number of studiesenlightedd the strong relationships between natural and cropped vegetation conditions and the relative NDVI data evolution in time.

Work done in North Italy confirmed these results and showed that NDVI is highly representative of plant photosynthetic capacity and efficiency.

So the main satellite data source used in this study is constituted by over 1600 daily images ofNormalised Difference Vegetation Index derived from NOAA 9 and, since November 1988, NOAA 11 satellites. This data set have been acquired for the time frame 1986-1990, mainly from the DVFLR station in Munchen (Germany) and by the University of Dundee (Scotland); from 1991 images were recorded directly by Telespazio receiving station in Scanzano (Sicily) that will continue to be the main supplier of project images in the operational phase.

Only images with a scan angle not exceeding 30° with respect to Italy have been used, this is a threshold that in our opinion will ensure to reduce bias in NDVI measures (Gupta 1992). A variable number of acquisitions have been performed in each year. However, in the average, 270 images (roughly an image every 1.4 day) a year, i.e. more than 70% time-coverage, are processed in order to represent with sufficientaccuracyy vegetation evolution. In general images are well distributed along each year, with a higher number in spring and summer months (April to September), the most important for the purpose of our analysis.

Raw data will be calibrated using corrected postlaunch coefficients supplied by NOAA and reported by Che and Price (1992).Navigation and then geometrically correction, assign to each pixel latitude and longitude values and worps the images in order to register it to a specific cartographic projection scale. The pixel's size obtained is about 1.1x1.1 km wide, with an accuracy of about 0.5 pixels at the ground.

TheNormalised Difference Vegetation Index is computed on a pixel by pixel basis (Perry and Lautenschlager, 1984, Gutman, 1987) for each image:

$$NDVI = \frac{channel2 - channel1}{channel2 + channel1}$$

Since NDVI time series have shown to be strongly influenced by several noises due to differences in atmospheric conditions, position of the sun and scan angle of the satellite, a method is required capable to reconstruct the true profile in accordance with a simple statistical model.

To this purpouse the outlliers detection is assessed by a Maximum Moving Window method that retain the maximum value recorded for a sliding time window. This method is considered an improvement of the Maximum Value Composite (MVC) method to analyse NDVI time series proposed by Holben and universally adopted (i.e. considering the maximum value assumed by the vegetation index in a fixed time period as a good estimate of the real vegetation observed NDVI value).

Furthermore the Maximunm Moving Window has revealed to be more efficient even of the recently proposed new methods (Viovy, Arino Belward 1992).

Putting together the maximum value of each month it is possible to build the annual vegetation index "Profile" of the observed pixel, outlining the dynamic evolution of the NDVI value through the year.

DATA STRATIFICATION AND AGRICULTURAL MONITORING AREAS CONSTRUCTION

In order to analyse data for significant agricultural areas with homogeneous crop and agricultural characteristics, the first operation to be performed is to construct a NDVI stratification containing similar vegetation composition and timing among the different dominant land covers present. These areas represent different photosynthetic potential and productivity levels that can be used in order to decrease data variability and, at the same time, increase estimation accurancy.

In order to eliminate the bias due to particular climatological conditions of each single year, the mean value of each month in the 8 years (1986-1993) will be used. After that a k-means unsupervised cluster anlysis has been performed. This approach has proved to be the best way to get a sharp definition of the classes found and to differentiate them as much as possible

(Benedetti, Rossini, Taddei 1992). In this way it is possible in fact, for the Italian environment, to differenziate simultaneously for biomass production and phytophenology.

NDVI stratification must be merged with administrative borders, that in theis case are represented by the "Regioni Agrarie" or "Agricultural Regions" (referred to AR hereafter), which are the smallest areal units in which ISTAT (Italian department of statistics) collects data on land-use and crop yield (ISTAT 1958). They are sub-province areal units homogeneous, in a wide sense, with respect to the altimetric zone in which they are included (internal or coastal mountains, internal or coastal hills, flat countries), with respect to climate, soil, morphology, phytogeography, etc., for type of production and land utilization system.

In South Italy 8 regions are present (NUTS 2), with 34 provinces (NUTS 3) and with 281 Agricultural Regions.

NDVI stratification data are merged with AR data in order to obtain Agricultural Monitoring Areas (AMA) on which extract vegetation index profile, and monitor observed crop.

NDVI BASED YIELD ESTIMATE AND FORECAST

Vegetation index dynamics in time has been found to be correlated with Canopy Leaf Area Index, LAI, and Gross Assimilation Rate (see fig.1).

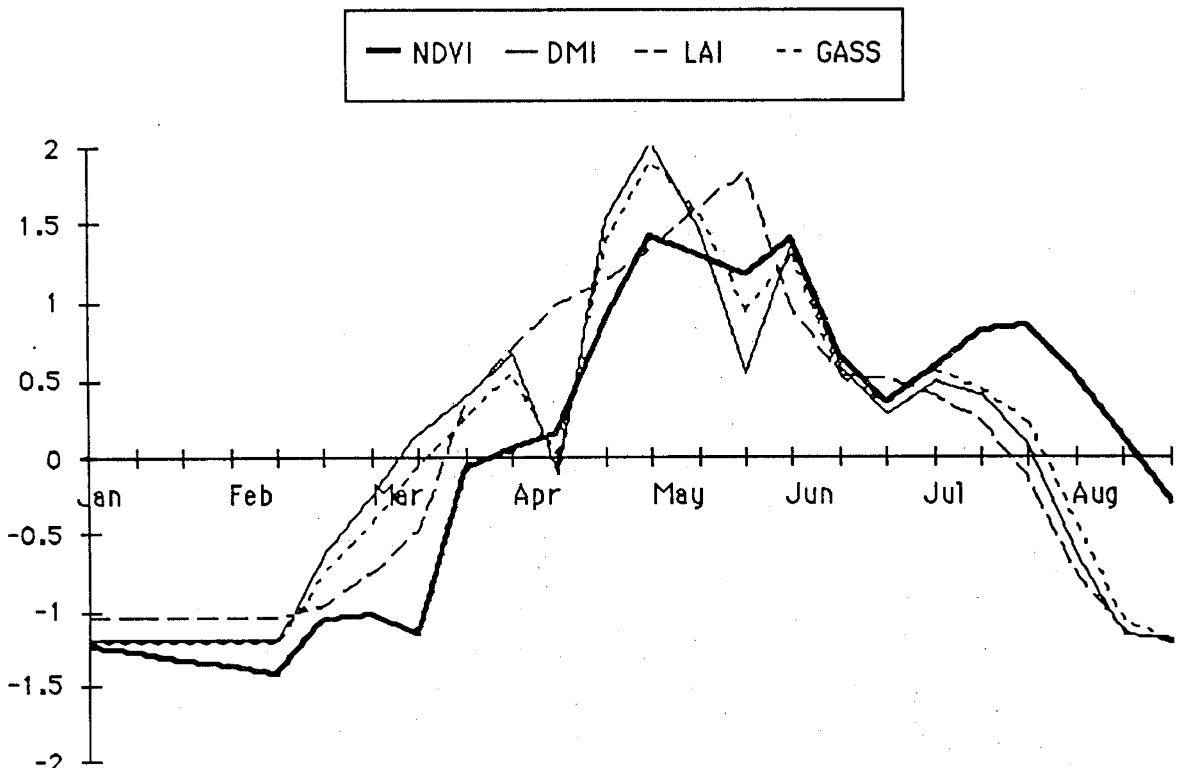

Figure 1: Comparison between simulated crop parameters and NDVI profile, Standardized values (after Benedetti, Rossini 1992).

These variables are strongly conditioned by the behaviour of precipitation, temperature and daily radiation of the observed area. Vegetation index therefore is representative of plants' reactions to changes in meteorological and environmental parameters.

Strong evidences were also found on vegetation index correlation with plant phenology. Phenological changes in time have been detected by NDVI for cultivated and natural vegetation in normal and exceptional years (Malingreau, 1986, Lloyd, 1989, Rossini, Benedetti, Taddei 1993).

The general pourpose is to select and identify some characteristics of the vegetation index profile indicative of the agricultural year performance, and to derive information potentially useful for determining the final crop yield.

Previous work done on wheat has shown that yield formation, few days after flowering, passes through a stage called grain filling (Grain Filling Period Duration, GFPD), that lasts till the wax ripeness stage, when the vast majority of substances accumulation in storage organs is completed. In this stage the last leaf, i. e. the top one called "Flag leaf", the ear and the last internode, produce up to 85% of the substances stored in the caryopsis (Rea, Calè 1991). In table n. 1 it is reported the results obtained in a 1986 Italian study on wheat. The flag leaf together with the second leaf have the highest photosynthetic activity of the entire plant through the whole filling period.

Date	Phenology	Leaf N°	Net Photosynthesis (mg CO2 m-2 s-1)	Stomatal Res. (s cm-1)	Actual transp. (mg H2O m-2 s-1)
17-apr	Coming into Ear	Flag (1°)	1,0130	0,9730	86,25
	(beginning)	2°	0,7862	1,0539	91,89
		3°	0,4419	2,4190	78,02
23-apr	Coming into Ear	Flag (1°)	0,8623	1,5880	101,43
		2°	0,2675	5,7980	35,12
28-apr	Flowering	Flag (1°)	0,6784	2,5520	62,07
	(beginning)	2°	0,2793	5,3930	40,10
8-may	Flowering	Flag (1°)	0,6446	2,6720	67,02
		2°	0,2817	5,2530	37,12
19-may	Milk Ripeness	Flag (1°)	0,4075	3,7830	45,12
		2°	0,1104	7,9560	26,08

Table 1: Effect of Leaf Age and position on net Photosynthesis in Triticum vulgare cv. Pandas (After Rea E. and Calè M.T. 1991)

As a consequence events that reduce the duration and the efficiency of the vegetative apparatus capacity in this period, whatever the origin, seriously jeopardize wheat production. Since the vegetation index measures the photosynthetic efficiency of the vegetative apparatus and in particular of the first leaves and organs, it is indirectly correlated with wheat yield in the period between flowering and wax ripeness.

Using these results a simple linear regression model can be derived for wheat yield estimate and forecast based on NDVI profile integration during wheat GFPD for each Agricultural Estimation Area.

Regression coefficients can be obtained using current year data for those areas where crop coverage is prevalent. In Emilia Romagna Region areas with more than 30 % of total agricultural used land have been considered.

Once the regression coefficients are obtained yield estimation can be extended for each A.M.A. to the whole south Italy area.

This method, however requires a year by year pre-calibration using official statistics data that are not always quickly obtainable.

An alternative is to use this model to forecast wheat yield at harvest time, without a year by year pre-calibration. In this case it is necessary to fix the model parameters, i.e. slope and intercept, using historical data .

Estimated and forecatsed production values can be obtained multiplying yield estimate and forecast for the official statistics data on crop acreage.

The results obtained in Emilia Romagna showed that the model outputs for production forecasting, without a year by year pre-calibration, present a relative difference with official data greater than 10 % in some years, but lower than 19% (see tab.2). For what concern wheat production estimate the differences with official statistics are not bigger than 7.4% (see tab.3).

YEAR	ISTAT	FORECAST	RELATIVE DIFFERENCE
1986	1195	969	-18.9 %
1987	1332	1187	-10.9 %
1988	1069	937	-12.3 %
1989	947	980	3.5 %

Table 2: Wheat production forecast in Emilia Romagna lowland area.(data in thousands of tons) (Benedetti, Rossini, 1992)

YEAR	ISTAT	ESTIMATE	RELATIVE DIFFERENCE
1986	1195	1223	2.3 %
1987	1332	1300	-2.4 %
1988	1069	1117	4.4 %
1989	947	876	-7.4 %

Table 3: Wheat production estimate in Emilia Romagna lowland area.(data in thousands of tons)(Benedetti, Rossini, 1992)

From an operative point of view this methodoogy can be used to assess a rough wheat yield forecast jet in June before harvest, followed by a more accurate yield estimate after harvest as soon as data on those Agricultural Region more relevant are available.

CONCLUSIONS

This methodology is stronghly based on the following condition : CROP SPECIFIC DOMINANCE .

This is the most important constraint that can determinate success or failure of work done. The crop considered must be dominant in the key period relevant for its yield determination. In Emilia Romagna in fact, vegetation dynamic in the agricultural area was dominated by wheat till the end of May, when sugar-beet and later maize and soybean, begin to increase their biomass. In fact till that time the fields, where these crops are cultivated, are ploughed or covered only partially by emerging plants. It was possible to conclude so that wheat is dominant from a radiometric point of view, even if it covers not more than 30% of pixel area, as during quite all its growing season there is not any other green biomass .

Other crops with different growing cycle, and particularly with different yield key period could not respect this condition .

In this project crop monitoring will be attempted extensively only on wheat. At local level an estimate will be attempted too for some important erbaceous crop, olive and citrus tree-crops.

Results obtained in the previous work, showed the potential utility of this method for a real-time and cheap crop monitoring . However a lot of work has to be done yet taking into account the different environments of South Italian area.

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