LANDSAT TM AND AGROMETEOROLOGICAL DATA FOR WHEAT YIELD ESTIMATION AT THE FARM LEVEL

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ABSTRACT

Wheat plays an important role in the Brazilian commodity production. Therefore, objective and reliable methods for yield estimation are needed specially at the farm level where several management actions have to be taken. LANDSAT TM and agrometeorological data were integrated in order to obtain a model for wheat yield estimation at the farm level for a test site in the south of São Paulo State. LANDSAT data for the crop years of 1986 (three acquisitions) and 1987 (two acquisitions), agronomic and meteorological data were related to yield estimates at the field level (200 fields approximately). Results have shown that vegetation index derived from LANDSAT TM explained 60 and 40 percent of wheat yield variability for the crop years analyzed. The joint use of both vegetation index and agrometeorological data in a single model improved significantly the results as compared to either vegetation index or agrometeorological data separately. The proposed model is to be validated for future crop seasons nevertheless it provided objective and accurate results for wheat estimation on the two crop seasons analyzed.

1. INTRODUCTION

The availability of accurate information on crop yield is essential in different sectors of agriculture. The correct decision processes at a variety of managerial levels are dependent on timely and accurate information. Crop yield models are designed to represent in a simple manner the relationship between the crops and their environment (Baier, 1979). At present, the existing growth models are not suitable to simulate perfectly the overall impact of meteorological and cultural factors on crop yields. On the other hand it is difficult to obtain timely and precise field observation on crop information over large areas to estimate potential yield (Colwell, 1979). Lately researches have been performed on the suitability of digital MSS and TM LANDSAT data to estimate crop yields. The high correlation between spectral reflectance of crops and agronomic variables encouraged the application of those data on crop yield models (Tucker et alli 1980, 1981, Richardson et alli 1982, Wiegand et alli 1979, Hatfield 1981, 1983 among others). Although most of those researches have been performed on experimental fields using ground based radiometers, Wiegand et alli (1979) suggested that remote sensing data from satellite are ready to be used in crop yield estimation models.

However improvement in the relationship between Landsat data and yield is dependent on research aiming the suppression of atmospheric effects and radiometric calibration. The several meteorological and cultural factors which affect the crop yield are indirectely observed through the vegetation index which is a visible and infrared multispectral band transformation able to express crop growing conditions and crop yield. Previous research (Richardson et alli, 1982, Barnett and Thompson, 1982, Rudorff 1985, among others) shows that the use of spectral data along with agrometeorological data provide better crop yield estimate as compared to those derived from just agrometeorological data.

Based on this research line, this study was performed to assess the improvement on wheat yield estimation at the farm level by using vegetation index derived from Landsat data along with agrometeorological data modelling.

2. METHODOLOGY

The study area is located in the main wheat production area in São Paulo state. The central geographical coordinates of the area are 22°30'S and 50°30'W. The weather is wet warm and without a dry season, with 350mm of average total precipitation from April to September. The average temperature for the warmest month (January) is over 24°C and for the coldest month (July) is less than 17°C (Setzer, 1966).

In Brazil wheat is planted as a winter crop, the main producers are states of Rio Grande do Sul, Paraná and São Paulo which respond for 98% of the brazilian production. Nevertheless this production is far lower than the domestic demand, what places Brazil as the fourth largest world importer of wheat (Fernandes, 1983).

In the study area the wheat is generally cultivated after the soybeans's harvest from late April to early May. The most planted varieties are Anahuac and BH 1146. The first is more productive but sensitive to water supply and soil fertility with a cycle of 120 days. The second is less productive but tolerant to dryness and lower soil fertility; its cycle is 100 days long.

In the study area 125 and 127 farms were selected during the crop year of 1986 and 1987, respectively. Crop field size in those farms varies from 10ha to 50ha. For each crop field the following data were collected : planting and harvesting date, variety, observed yield in kg/ha and geographical boundaries of each crop area on the imagery.

For the crop year of 1986 the following TM-Landsat overpasses were acquired: June, 8th, June, 24th and July, 10th. For the crop year of 1987 the TM-Landsat dates used were June, 27th and July, 13th.

TM imagery were digitally processed on the multispectral image analyser IMAGE-100 at the scale of 1:50.000 so as to obtain full resolution (1 pixel on the image corresponding to one pixel on the IMAGE-100 display). The digital number average and variance were acquired for each crop field located on the image in bands 3 and 4. The average digital number for each band was converted to reflectance using the approach described in Brain and Barker (1987). The reflectance values were than transformed into the RVI vegetation index, which correspond to the ratio between band 4 and band 3. This index is supported by Tucker (1979) for crops with more than 50% of ground cover.

Those vegetation indices were correlated to the observed yield in selected farms including different varieties of wheat and planting dates. The vegetation index, per si gives yield estimation. However the application of those indices along with yield estimation derived from agrometeorological models can improve the results. With this objective, an agrometeorological model was adapted to wheat using the approach suggested by Doorembos and Kassam (1979). The model description and software are reported in Rudorff and Batista (1988). The model estimates the maximum expected yield as a function of temperature and radiation during the crop cycle and considering that all the remaining factors such as fertility, seeds, disease control are adequate to the crop.

This maximum yield is then damaged or not as a function of water supply. Since in this computation the potential production of different varieties is not considered, a factor was applied to adjust the estimate to that potential production of the main varieties present in the study area.

Finally the yield model is developped by relating crop yield estimates derived from agrometeorological model and vegetation index with the observed yield of selected fields.

3. RESULTS AND DISCUSSION

Spectral data from TM present high spatial resolution allow to estimate reflectance variability among small crop fields. The vegetation index aims to simply express the balance between incident, absorded, reflected, and transmitted energy by a given crop. This balance varies according to different phenological stages.

The RVI resulting from the ratio between TM band 4 and TM band 3 will increase as crop reflectance increases in band 4 and decreases in band 3. In the band 4 the leaf cell structure is the major responsible for reflectance levels, whereas in band 3 leaf pigments respond for the absorption of the incident energy, resulting in lower reflectance. It is generally expected that increases in the vegetation index represent increases in the photosynthetic activity of a given crop what causes higher grain yield. Thus it is possible to relate vegetation index to crop yield. Variation in that relationship along the crop cycle, however are not well known. Considering the low frequency of Landsat overpass (16 days), high frequency of cloud cover and the quite short length of the wheat cycle (100 days), data availability for such analysis is limited.

Vegetation Index - 1986

The crop year of 1986 was a nice year for data acquisition with three overpasses during the length of the wheat cycle. At the first overpass most of the planted land were 35 to 45 days old. The following overpass were obtained at 16 days intervals according to satellite track pattern. Vegetation indices were produced for each of these dates and regressed against crop yield. The results can be observed on Table 1. Data from June, 24th present the best results with vegetation index explaining 64% of the yield variation. At that date almost all crop fields were 50 to 60 days old. To assess the impact of wheat variety on that relationship statistical analysis was performed for the vegetation index of the best date for each variety: Anahuac and BH 1146 planted in the period of April 21 to 25. The effect of variety and planting period on the relatioship is not constant. The improvement in the relationship resulting from these variety and planting period homogenization was very significant, however results do not support using variety-planting period "homogenization" for modeling purposes because some "homogenization" gave very poor results.

June and July, 1986, were very dry periods. As a result, the planting date strongly influence crop yield (Figure 1a). The average of the vegetation index decreased along the crop cycle as a response to the decrease in crop yield.

Vegetation Index - 1987

The crop year of 1987 was also a nice year for Landsat data acquisition. Taking into account the experience gained with 1986 data analysis, only two, overpasses were selected. June, 27th, and July 13th, which are almost anniversary dates in relation to the 2nd and 3rd overpasses of 1986.

Table 1 shows the results of the correlation between vegetation index and crop yield in 1987. The best results were found for June 27th, 1987 overpass. Data were also stratified according to the planting date to assess the impact of this variable on the relationship between vegetation index for Anahuac variety and its crop yield. Results on Table 1 show that the degree of relationship varied from one planting period to the other. For fields planted in the period April 16-20 there was an increase in the relationship whereas fields planted in the period May 06 to 10 displayed no significant correlation at 5 percent level.

During the crop year of 1987 there was a suitable rain distribution from seeding to maturation, followed by a dry period at the harvest independent of the planting period. On Figure 1b one can observe some variation in yield for different planting periods with the vegetation index being sensitive to those yield changes.

TABLE 1

REGRESSION ANALYSIS OF OBSERVED YIELD AND VEGETATION INDEX (RVI) FOR 1986 AND 1987

YEAR	NUMBER OF SAMPLES	ACQUISITION DATE (DAY/MONTH/YEAR)	CORRELATION COEFFICIENT (r)	COEFFICIENT OF DETERMINATION (r^2)	STANDARD ERROR (ton/ha)
1986	125[a]	08/06/86	0.68	0.46	443
		24/06/86	0.80	0.64	366
		10/07/86	0.73	0.54	411
	30[b]	24/06/86	0.86	0.74	295
	17[c]	24/06/86	0.89	0.79	166
1987	127[d]	27/06/87	0.67	0.46	290
		13/07/87	0.43	0.19	353
	18[e]	27/06/87	0.75	0.57	243
	13[f]	27/06/87	0.55	0.31*	342

a - Sample with all wheat fields of 1986 crop season.

b - Sample with only Anahuac variety planted from April 21 to 25, 1986.

c - Sample with only BH 1146 planted from April 21 to 25, 1986

d - Sample with all wheat field of 1987 crop season.

e - Sample with only Anahuac variety planted from April 16 to 20, 1987.

f - Sample with only Anahuac variety planted from May 06 to 10, 1987.

* - Not significant at α = 0,05.

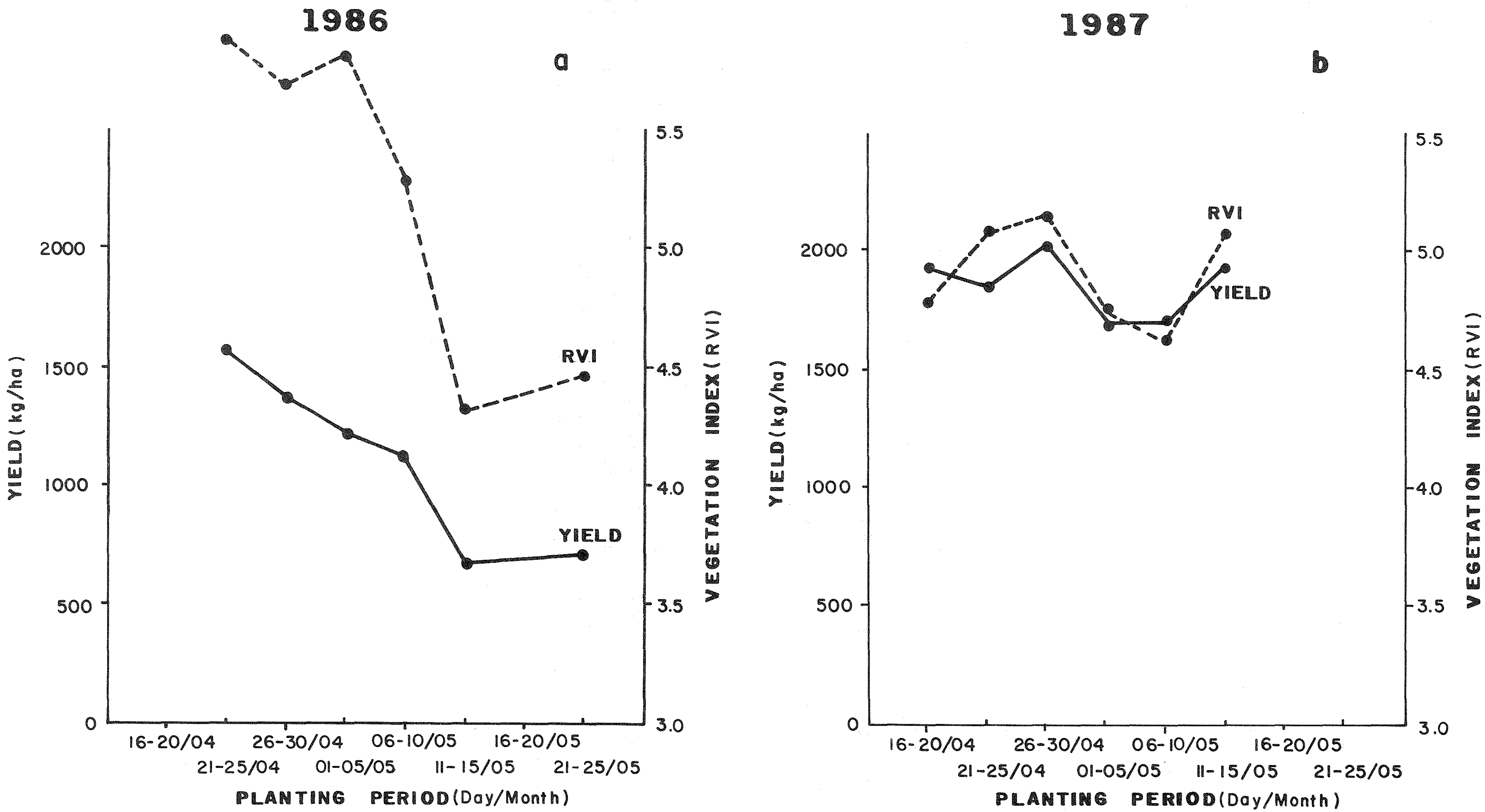

Fig. 1 - Average of observed yields and average of vegetation indices as a function of planting period.

Vegetation Index - 1986 and 1987

The comparison between the crop year of 1986 and 1987 is eased by the availability of images at anniversary dates. This fact shows that the best image date for 1986 is also the best for 1987. However the value of vegetation index are quite different from one crop year to the other as shown on Figure 1a and b. The vegetation index in 1986 is 11% higher than that of 1987 whereas the yield of 1986 is 28% lower than that of 1987. Analysing pluviometric data for 1986 one can observe that there was no rain during the month previous to the Landsat overpass. For 1987, however intense rains were registered previously to the Landsat overpass by July, 15th (230mm) and July, 23th (36mm). The differences in rain distribution are mainly responsible for the instability of the relationship between vegetation index and crop yield for different crop years.

The attempts to minimize variations between dates were restricted to atmospheric correction and sensor calibration. Differences related to soil moisture however could be visually observed by means of changes in soil tonality. At that crop stage the reflectance is also influenced by soil reflectance making the image tonality become lighter in 1986 and darker in 1987 owing to the higher soil moisture.

In spite of the existing differences in vegetation indices between dates which are not related to crop itself they explained 48% of the variation of the observed yields with a standard error of estimate of 414kg/ha.

Agrometeorological model

The agrometeorological model, allowed to calculate the maximum yield for wheat as a function of radiation and temperature from seeding to the harvest. This maximum yield was then damaged for the water availability what resulted in the estimated yield for a generical wheat variety. To adjust this yield to the potential yield for different wheat varieties, a multiplicative factor derived from ground information was applied as follows: Anahuac = 1.30, BH 1146 = 0.90, IAC 5 = 1.00, IAC 18 = 1.00 and PAR 281 = 0.65. As a result the agrometeorological model produced different yields as a function of seeding date, wheat variety, radiation, temperature and soil water availability.

The agrometeorological model can be applied for both local and regional scales. Comprehensive meteorological data used in this work were provided for a single meteorological station, except for the pluviometric data which were available in three different stations. Because of that the model was not sensitive to variation in yield among different crop fields.

The estimated yield produced by the agrometeorological model was regressed against the observed yield resulting in an explained variation of only 33% and 18% and in a standard error of estimate of 495kg/ha and 355kg/ha for 86 and 87, respectively. The regression using data from both years (86 and 87) resulted in a explained variation of 43% and a standard error of 434kg/ha.

The proposed model

The agrometeorological model did not explain variation in yield caused by meteorological variations within the study area mainly owing to its low spatial resolution. On the other hand, the vegetation index could not explain variation in yield occuring along the crop cycle since it was available for one or two dates.

By combining the high temporal resolution of meteorological data and high spatial resolution of Landsat data a new model was derived producing an increase in the explained variation from 43% (agrometeorological model) and 48% (vegetation index) to 65% (agrometeorological and vegetation index). The standard error of estimate decreased to 339kg/ha for an average yield of 1581kg/ha.

4. CONCLUSIONS

1) Out of the three analysed dates for 1986 the best was June, 24th.
2) Out of the two analysed dates for 1987 the best was June, 27th.
3) The best results were derived from just one single date acquisition, corresponding to the same planting period for both years analysed.
4) The agrometeorological model explained 33% and 18% of the yield variation for 1986 and 1987, respectively, and 43% for both years.
5) The vegetation index explained 64% and 46% of the yield variation for 1986 and 1987, respectively, and 48% for both years.
6) The proposed model increased the explained variation to 71% and 53% for 1986 and 1987, respectively, and to 65% for both years.
7) The incorporation of vegetation index to the agrometeorological model significantly improved the yield estimates at crop field level.

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