MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO DE PESQUISAS ESPACIAIS

AUTORIZAÇÃO PARA PUBLICAÇÃO
AUTHORIZATION FOR PUBLICATION

PALAVRAS CHAVES/KEY WORDS

REMOTE SENSING	*SUGARCANE*
CROP PRODUCTIVITY	*MSS-LANDSAT*

AUTORIZADA POR/AUTHORIZED BY
Marco Antonio Raupp
Diretor Geral

AUTOR RESPONSAVEL / RESPONSIBLE AUTHOR
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DISTRIBUIÇÃO/DISTRIBUTION
☐ INTERNA / INTERNAL
☒ EXTERNA / EXTERNAL
☐ RESTRITA / RESTRICTED

REVISADA POR / REVISED BY
Dalton de M. Valeriano

CDU/UDC
528.831:633.61

DATA / DATE
December 1988

PUBLICAÇÃO Nº / PUBLICATION NO
INPE-4733-PRE/1409

ORIGEM / ORIGIN
DPA

PROJETO / PROJECT
CANASAT

Nº DE PAG. / NO OF PAGES
14

ULTIMA PAG. / LAST PAGE
13

VERSÃO / VERSION

Nº DE MAPAS / NO OF MAPS

TÍTULO/TITLE

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RESUMO-NOTAS/ABSTRACT-NOTES

Landsat data have been used to correlate with LAI, green biomass, percent ground cover, plant population, chlorophyll concentration and plant height for rangeland pasture, wheat, and soybeans. In this study multitemporal spectral information of sugarcane obtained during the crop year 1982-1983 were correlated with cane production and the possibility of using LANDSAT data for yield estimation was evaluated. Sun elevations of the eight LANDSAT data dates were corrected to 44^{o} and the digital counts of the 24 sugarcane fields were acquired using an interctive image analysis system for each MSS channel. Correlation analyses were applied to cane yields and vegetation indices (i.e., D57, R75, TVI and PVI) that were derived from single or multidate LANDSAT spectral data. Significant correlation coefficients were found, however, amplitudes of the correlation coefficients were not high enough for a direct application on sugarcane yield estimation.

OBSERVAÇÕES/REMARKS

+ *Paper presented at the 3rd Brazilian Symposium on Remote Sensing, Rio de Janeiro, 28 a 30 Nov. 1984.*

* *Presentely a graduate student of the University of Michigan. Ann Arbor.* -

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ABSTRACT

LANDSAT data have been used to correlate with LAI, green biomass, percent ground cover, plant population, chlorophyll concentration and plant height for rangeland pasture, wheat, and soybeans. In this study multitemporal spectral information of sugarcane obtained during the crop year 1982-1983 were correlated with cane production and the possibility of using LANDSAT data for yield estimaton was evaluated. Sun elevations of the eight LANDSAT data dates were corrected to 44^o and the digital counts of the 24 sugarcane fields were acquired using an interactive image analysis system for each MSS channel. Correlation analyses were applied to cane yields and vegetation indices (i.e., D57, R75, TVI and PVI) that were derived from single or multidate LANDSAT spectral data. Significant correlation coefficients were found, however, amplitudes of the correlation coefficients were not high enough for a direct application on sugarcane yield estimation.

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1 - INTRODUCTION

Accurate crop yield is an important factor for the forecast of agricultural production. There are many approaches for yield estimation; Baier (1979) classified these approaches in three categories: mechanistic-type crop growth simulators, statistically-based crop-weather analysis models and multiple regression yield models. Numerous publications are found using these approaches and each of these methods has its advantages and disadvantages. Since the launch of LANDSAT in 1972 a new approach for large area yield prediction becomes available using satellite provided spectral data. At the beginning, experiments were performed correlating LANDSAT spectral data to yield related parameters such as; total standing biomass, leaf area index (LAI), percent ground cover, plant height, plant population etc. (Pearson and Miller, 1972; Rouse et al., 1973; Weigand et al., 1974; Deering et al., 1975 and Weigand et al., 1979). Later, attempts were made to relate LANDSAT spectral data directly to grain yield. Significant correlations were obtained between spectral data derived vegetation index and grain yield of wheat (Colwell et al., 1977) and sorghum (Richardson et al., 1982). The rationale behind this application is that the secondary productivity is mainly proportional to vegetative productions which are correlated to LANDSAT derived vegetation indices. Colwell et al. (1977) proposed a one-step crop production forecasting system where LANDSAT green measures for all pixels (i.e., wheat and non-wheat) are summed to obtain the estimate of total production without going through the usual crop identification, acreage estimation and yield prediction procedures. In addition to the direct application, LANDSAT spectral data can also be used to estimate vegetative variables (e.g., LAI, phenological stage etc.) which are used as inputs to crop growth or evapotranspiration model and, thus, providing yield information in an indirect manner (Kanemasu et al., 1977, Brakke and Kanemasu, 1979, Weigand et al., 1979).

The energy crisis of the World makes sugarcane (*Saccarum officinarum*) an important crop for Brazil due to its ethanol-alcohol production which substitutes the imported petroleum. For years, efforts have been directed to sugarcane acreage estimation using LANDSAT data and a methodology based on visual interpretation of multidate LANDSAT imagery has been developed (Mendonça et al., 1981); nevertheless, cane yield information has not been available in the crop forecasting system. The objective of this study is to determine the extent to which LANDSAT spectral data can be directly used, as an indicator in cane yeild forecasting. The fundamental propositions on which this study is based are: 1) the luxurious vegetative growth up to the early yield formation stage is favorable to final cane production due to the higher capability of intercepting photosynthetically active radiation and; 2) The quantity and quality of vegetation biomass can be provided by LANDSAT data.

2 - DATA ACQUISITION AND ANALYSIS

Color infrared aerial photographs (1:30,000) for Araçatuba, São Paulo State, were taken on June 18, 1983. Forty-two sugarcane fields larger than 50 ha were chosen from aerial photographs and their locations were marked on overlays and a topographic map of 1:250,000. The map and the overlays were sent to distilleries of the study area, so that information such as variety, plant/ratoon crop, planting acreage and the harvested cane tonnage for each selected field could be collected.

LANDSAT digital tapes (CCTs) were acquired for the dates Sept. 9 and Nov. 28 of 1982, Feb. 16, May 7, July 10, July 26, Aug. 27 and Sept. 28 of 1983. An interactive image analysis system (Image-100) was used to collect sugarcane spectral data. LANDSAT CCTs of the study area were enlarged to the scale of 1:100,000 on the image monitor. Drainage network and ponds were used as references for visual localization of the selected fields. Once sugarcane field was located on the image monitor, the electronic cursor was positioned at the center of the field and digital counts (DC) of the pixels within the cursor for each of the four multispectral scanner (MSS) bands were extracted and averaged through the "single-cell" program. The size of the cursor was determined according to the field size on which spectral analysis was made. In general, spectral means of 36 or 64 pixels were acquired. Besides the selected sugarcane fields, spectral information of soil, cloud and cloud shadows were also collected to construct Kauth's soil line (Kauth and Thomas, 1976), as indicated by Richardson and Weigand (1977). Solar elevations of the eight LANDSAT overpasses varied from 31^0 to 57^0. Thus, in order to eliminate the effect of solar elevation on LANDSAT data and to make the spectral comparison meaningful, the sine solar elevation correction algorithm of 44^0 was applied. No attempt was made to correct atmospheric effects. The sun elevation standardized digital counts of LANDSAT MSS bands were then used to calculated several commonly used vegetation indices (VIs): the difference or the ratio of MSS 5 and MSS 7, the transformed vegetation indices (Rouse et al. 1973), and the perpendicular vegetation indices (Richardson and Weigand, 1977). Definitions of the VIs are:

$$D57 = MSS5 - MSS7, \tag{1}$$

$$R75 = \frac{MSS7}{MSS5}, \tag{2}$$

$$TVI6 = \sqrt{\frac{MSS6 - MSS5}{MSS6 + MSS5} + 0.5}, \tag{3}$$

$$TVI7 = \sqrt{\frac{MSS7 - MSS5}{MSS7 + MSS5} + 0.5}, \tag{4}$$

$$PVI_{X,Y} = \sqrt{(R_{gg}X - R_pX)^2 + (R_{gg}Y - R_pY)^2}, \tag{5}$$

where:

PVI - is the perpendicular VI, defined as the perpendicular distance between the candidate vegetation point and the soil background line using band combination MSSX and MSSY;

R_p - is the reflectance of a candidate vegetation point for LANDSAT bands MSS5 or MSS7, and

R_{gg} - is the reflectance of soil background corresponding to a candidate vegetation point.

The paired data of cane yield (T/ha) and the DC of individual LANDSAT MSS band or the derived VI were correlated lineary for each LANDSAT pass. In addition, cumulative VIs were also tested because the integration of VI with time provides information not only about the magnitude of the VI value but also the persistance of photosynthetic active biomass during growth period. Better yield prediction results using multidate LANDSAT data have reported on wheat and barley (Pinter et al. 1981).

3 - RESULTS AND DISCUSSION

3.1 - CONSTRUCTION OF KAUTH'S SOIL LINE

There are two soil types in Araçatuba: Latosol and Podsol. These soils have similar spectral characteristics with a slightly higher reflectance found in Podsol soil - Lins - Marīlia. In order to construct soil line, fifty-two spectral data for soils, water, cloud and cloud shadow were determinated from CCT's of the eight LANDSAT overpasses. Kauth's plane of soil using all possible pairwise combinations of the four MSS bands are shown in table 1. Soil lines using band combinations of (4,6) and (4,7) were statistically the best due to high correlations and small standard deviations of regression. Richardson and Wiegand (1977) found that soil lines (5,6) and (5,7) were the best and they are often used in VI study. Thus, for comparison purposes, soil line (5,7) was also included in this study. Band combinations of (4,5) and (6,7) were eliminated from VI study due to the widely known fact that bands within visible and infrared regions are highly correlated. Thus, for the modeling of perpendicular vegetation index (PVI), soil lines (4,6), (4,7) and (5,7) were employed and the derived VIs were denominated PVI46, PVI47 and PVI57, respectively.

3.2 - VEGETATION INDEX STUDY

After data collections, it was noted that spectral or field data were absent in some of the 42 sugarcane fields due to cloud cover of

LANDSAT data (Nov. 28, 1982) or incomplete questionnaire. Through data screening, only 24 out of the 42 originally selected sugarcane fields were suitable for VI study. Information about sugarcane variety, cane yield and whether it was plant or ratoon crop for each of these 24 fields, are shown in table 2. It was decided to delete LANDSAT data of Sept. 9, 1982 because most of the ratoon crops were at the crop establishment stage, and the collected "sugarcane spectral data" were actually composites of soil and plant characteristics. The exclusion of LANDSAT data on Sept. 28, 1983 was due to the fact that, some of the fields had already been harvested by that time, inclusion of this LANDSAT overpass would trade-off by less sugarcane fields in the regression analysis. It is also important to point out that, for better scheduling of manual harvesting, it is a general practice to plant early and late sugarcane varieties in the same field. This means that the digital count obtained from each MSS band for each field was a mixture of spectral response of several sugarcane varieties. Thus, spectral data of five LANDSAT overpasses were used for VI study; they are Feb. 16, May 7, July 10, July 26 and Aug. 27 of 1983. It is believed that, during this period, collected spectral data demonstrated the conditions of photosynthetic active biomasses without the influence of soil reflectance.

Simple linear correlation coefficients between cane yield and seven vegetation indices (i.e. D57, R75, TVI6, TVI7, PVI46, PVI47 and PVI57), based on single date LANDSAT digital count, are presented in table 3. All VIs except PVI57 of Feb. 16 and Aug. 27 were significantly correlated ($\alpha = 0.05$) to cane yield. Homogeneity tests of the correlation coefficients showed no difference between or among any VIs of these two dates, indicating that VIs based on Feb. 16 were as good as that obtained on Aug. 28; prior to havesting. The significant correlations of VIs in February is because that sugarcane plantation normally reaches its maximum growth rate in this month (Machado et al., 1982). Thus, at this stage the differences in LAI are more pronounced than in the later yield formation stage when the active leaf area is declining. Cumulative VI models using multidate LANDSAT spectral data improved considerably the associations with cane yield (Table 4). All correlation coefficients were significant for any cumulative period, with the exception of PVI46 which was the less promising yield estimator. PVI47 and PV157 had similar performances. Statistical testing showed no superiorities of PVIs over D57, R75 and TVIs, which are less influenced by soil type or surface moisture content and much simpler to apply. Eventhough there was no statistically significant difference among r values of VIs based on single date or multidate LANDSAT data, there was a trend of a larger proportion of explained yield variation by accumulating VI toward the end of the growth period. The better performance of VIs integrating over a given period confirmed what was found by Tucker et al. (1981).

This is the first experiment testing the potential of LANDSAT spectral data on the yield estimation of a perennial crop. Sugarcane spectral data, which were the mixture of spectral responses of different varieties and planting dates (plant vs. ratoon crop), attributed to the low correlations between VI and cane yield in comparison to those presented in the literature, where only annual crops were involved. Results from this study show that associations between VIs and cane yields were significant; however, the amplitudes of the coefficients found preclude the direct application of vegetation indices to sugarcane yield estimate.

TABLE 1

KAUTH's SOIL LINES FOR ALL POSSIBLE PAIRWISE COMBINATIONS OF THE 4 LANDSAT MSS BANDS

MSS BAND PAIRWISE COMBINATION (X_1, X_2)	CORRELATION COEFFICIENT (r)	LINEAR EQUATION $X_1 = A_0 + A_1X_2$	STANDARD DEVIATION OF REGRESSION S_{X_1,X_2}
(4,5)	0.96	$X_1 = -21.66 + 0.95X_2$	12.36
(4,6)	0.98	$X_1 = -16.56 + 0.95X_2$	9.37
(4,7)	0.99	$X_1 = -5.60 + 1.02X_2$	7.43
(5,6)	0.97	$X_1 = 9.57 + 0.95X_2$	11.29
(5,7)	0.97	$X_1 = 21.21 + 1.01X_2$	11.39
(6,7)	0.99	$X_1 = 12.64 + 1.06X$	4.9

* Digital count (range 0-255) data are for Sept. 9 and Nov. 28 of 1982; Feb. 16, May 7, July 10, July 26, Aug. 27 and Sept. 28 of 1983 from soils, water, cloud and cloud shadows (n=52).

TABLE 2

INFORMATION OF THE 24 SUGARCANE FIELDS USED IN VEGETATION INDEX MODELING

NUMBER OF OBS.	VARIETIES*	PLANT (P) OR RATOON (R) CROP	CANE YIELDS (T/ha)$^+$
1	a, b, d.	R	111.36
2	a, d, f.	R	137.32
3	b, d, f.	P	116.20
4	b, f.	P	157.06
5	a, c, h.	P	145.66
6	a, b, f.	P	97.03
7	c, e.	R	69.73
8	a.	P	121.77
9	a.	P	103.15
10	a, c, d, f.	P	109.53
11	f.	P	145.24
12	b, f, g.	P	136.26
13	a, c, d, f.	P	117.32
14	d.	P	112.90
15	b, f.	P	114.99
16	d.	R	89.06
17	f.	R	111.99
18	a, d, f.	R	63.06
19	c. e, f.	R	90.31
20	a, c, d.	R	97.91
21	a, d.	P	133.42
22	a. b, h.	R	87.24
23	a. b, d.	R	54.37
24	g.	R	75.35

* (a) NA 56-79, (b) IAC 51-205, (c) IAC 52-150, (d) CB 41-76, (e) CB 47-355, (f) CP 51-22, (g) CB 49-260, (h) others.

+ Provided by distilleries.

TABLE 3

SIMPLE LINEAR CORRELATION COEFFICIENTS BETWEEN CANE YIELDS OF 24 SUGARCANE FIELDS AND SEVEN VEGETATIVE INDICES BASED ON SINGLE DATE LANDSAT DIGITAL COUNTS

DATE OF	LANDSAT MSS BAND OR VEGETATIVE INDEX									
LANDSAT PASS	MSS4	MSS5	MSS6	MSS7	D57	R75	TVI6	TVI7	PVI46	PVI47	PVI57
Feb. 16	-0.30	-0.39	0.28	0.42*	-0.46*	0.48*	0.41*	0.44*	0.46*	0.45*	0.37
May 7	-0.44*	-0.46*	0.08	0.00	-0.32	0.51	0.43*	0.51*	0.32	0.32	0.22
July 10	-0.29	-0.25	0.29	0.39	-0.35	0.33	0.30	0.34	0.35	0.38	0.33
July 26	-0.40*	-0.36	0.12	0.18	-0.24	0.27	0.22	0.27	0.24	0.24	0.19
Aug. 27	-0.12	-0.33	0.38	0.43*	-0.41*	0.41*	0.43*	0.43*	0.44*	0.40*	0.35

* Significant at $\alpha = 0.05$.

TABLE 4

SIMPLE LINEAR CORRELATION COEFFICIENTS BETWEEN CANE YIELDS AND CUMULATIVE VEGETATION INDICES

BASED ON MULTIDATE LANDSAT DIGITAL COUNTS OF 1983 (n=24)

NUMBER OF CUMULATIVE LANDSAT DATA*	ADDITIONAL LANDSAT PASS	LANDSAT MSS BAND				VEGETATION INDEX						
		MSS4	MSS5	MSS6	MSS7	D57	R75	TVI6	TVI7	PVI46	PVI47	PVI57
1	-	-0.30	-0.39	0.28	0.42*	-0.46*	0.48*	0.41*	0.44*	0.37	0.45*	0.46*
2	May 7	-0.46*	-0.48*	0.05	0.21	-0.45*	0.54**	0.46*	0.50*	0.33	0.44*	0.45*
3	July 10	-0.48*	-0.50*	0.15	0.33	-0.52**	0.57**	0.50*	0.55**	0.42*	0.52**	0.52**
4	July 26	-0.51**	-0.53**	0.17	0.33	-0.49*	0.55**	0.48*	0.53**	0.40*	0.49*	0.49*
5	Aug. 28	-0.53**	-0.58**	0.27	0.42*	-0.56**	0.59**	0.56**	0.59**	0.42*	0.52**	0.59**

+ Using LANDSAT overpass of Feb. 16 as data base.

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

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