

# SATELITE MONITORING OF SOIL MOISTURE UNDER SUGAR CANE

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## ABSTRACT

The desire to be able to forecast yield over a large area was revived with the introduction of satellite technology. The yield model concerned is the one which utilizes accumulated stress index. The only factor in the model which could vary over an area, is the actual evapotranspiration. This paper is an attempt to evaluate the possibility of using satellite data to estimate soil moisture. The diurnal changes of soil moisture in the area, is the ETA. Samples of leaves and soil were taken to determine leaf water content and soil moisture respectively, while OCT data were selected for cloud free image of the area of study. The digital data of the image were then regressed on the leaf water content and on the soil moisture. The results show that the satellite data represent very well both the leaf water content and the soil moisture. Band Ratio 2 would give better estimate of the leaf water content, while for the soil moisture, Band Ratio 1 is the best estimator. An ambitious programme had been launched in the 70's to monitor area planted to, and crops' growth in the United States. This has provoked similar ambition in other countries, including Indonesia, to monitor crop growth and development. This eventually would lead to forecasting yield over a large area. Yield, has been shown to be linearly related to soil moisture stress (Dale & Shaw 1965, Shaw 1974 and Shaw 1978). As defined by Dale and Shaw (1965), moisture stress is a relative measure of the deficit of actual evapotranspiration and potential evapotranspiration. Thus if ETA is the actual and ETP is the potential evapotranspiration, then

$$1 - \text{ETA/ETP}$$

is the moisture stress index for the period under consideration. The yield, then would be related to the accumulated moisture stress index over the growing period. Given that ETA and ETP could be estimated for any given day, accumulation over part or over the whole growing season could be accomplished and yield estimated for the crop. ETA could easily be estimated from the soil moisture status from two points in time, i.e.

$$\text{ETA} = s_{x-1} - S_x \quad \begin{array}{l} s_{x-1} : \text{antecedent soil moisture} \\ S_x : \text{present soil moisture} \end{array}$$

ETP is assumed to be conservative for several kilometers around, given a homogenous terrain. It could be estimated using surface data from the class A pan, or through either the Thornthwaite or Penman formula.

This paper is part of the effort to estimate moisture stress, i.e. ETA. Its purpose is to relate soil moisture conditions to the spectral responses of the NOAA Satellite AVHRR bands.

Several attempts have been made to relate surface conditions to the spectral responses of the satellite. The most successful one during the last decade is the one using normalized difference vegetation index or NDVI. NDVI has been used by Hapip et al. (1988) to monitor the forest coverage in Kalimantan. LAPAN (1987) used it to delineate areas which experienced drought in 1987.

Key Words : Satellite monitoring, soil moisture, NDVI, Band ratio sugar cane

## DATA AND PROCEDURES

The study was conducted in the sugar cane plantation Gunung Madu in the Lampung province. Soil moisture data were monitored using the gravimetric method and tensiometers. Samples were taken from a depth of 15 cm. In one division, further referred to as Division 1, the cane was 3 month old, while in Division 2, the crop was 4 month when the soil moisture data began to be collected. Concurrently - plant water content, viz. leaf water content data were collected. Ten samples of each were taken every three days to represent the condition at each division.

Hardcopy satellite data were then selected for cloudfree coverage of the sugar cane plantation. These were further geographically corrected to obtain the correct pixels representing

the area of the plantation. The values of channel 1 and 2 were taken to calculate the following :

1. NDVI =  $(Ch\ 2 - Ch\ 1) / (Ch\ 2 + Ch\ 1)$
2. BR1 =  $Ch\ 2/Ch\ 1$
3. BR2 =  $Ch\ 1/Ch\ 2$

Using values of these three measures, regression analyses were made on the soil moisture and leaf water content observed.

### RESULT AND DISCUSSION

Figures 1 and 2 show the soil moisture and leaf water content in Division 1 and 2 respectively. In general the trend of both could be said to parallel each other. However some discrepancies are discernible, such as that of the 7th and the 18th observations in Division 1, and that of the 22nd observatio in Division 2.

These could be observational errors, although it could also be due to the small infiltration rate of the rainfall occuring on the 4<sup>th</sup> and the 5<sup>th</sup> observations amounting to 5 mm and 6 mm respectively in Division 1. Data showing the departures were therefore not eliminated. This notion is supported by a highly significant correlation coefficient of 0.95 between soil moisture and leaf water content one day after, in Division 1 and of 0.96 in Division 2.

Regressing NDVI on soil moisture and on leaf water content, resulted in the following; Table 1 and Table 2.

Table 1. Regression of NDVI (y) on soil moisture (x)

Division	Regression Equation	r	Status of Y
1	$\cos(Y-Y) = .971 + .297X - 4.65X^3 *$	.71	Lag = 0 day
	$\cos(Y-Y) = .958 + .447X - 7.69X^3 *$	.76	= 1 day
	$\cos(Y-Y) = .959 + .455X - 8.89X^3 *$	.63	= 2 days
2	$\cos(Y-Y) = .172 + 1.90X - 1.49X^3$	.56	Lag = 0 day
	$\cos(Y-Y) = .923 + .879X - 16.7X^3 **$	.83	= 1 day
	$\cos(Y-Y) = .371 + 1.46X - 1.16X^3$	.68	= 2 days



As shown by Table 1 the best fit is the regression with time lag of one day. This is obvious since what the satellite sensed, was the reflection by the surface, which in this case was the sugar cane canopy. As is known, channel 1 senses the wavelength 0.580 to 0.662 m, while channel 2 tthe wavelength 0.725 to 1.100 m. These are the domain of solar radiation. The reflection of these parts of the radiation is greatly affected by the crops' moisture content (Baharsja *et al.* 1982).

Best fit with time lag of one day is consistent with what has been stated previously about the correlation between leaf water content and soil moisture condition. This means that regression of NDVI on leaf water content would be best without time lags.

Table 2. Regression of NDVI (Y) on leaf water content (X)

Division	Regression Equation	r	Status of Y
1	$Y = -1.92 + 6.69X - 5.20X^3$ *	.75	Lag = 0 day
	$Y = .17 + 1.90X - 1.49CX^3$	.76	= 1 day
	$Y = .37 + 1.46X - 1.16X^3$	.68	= 2 days
2	$Y = .36 + 2.97X - 2.10X^3$ **	.80	Lag = 0 day
	$Y = .26 + 1.64X - 1.19X^3$	.52	= 1 day
	$Y = .75 + .59X - .48X^3$	.54	= 2 days

As expected, leaf water content with no lag shows better fit than those with lag one or two days. Better fit in terms of significancy and the magnitude of the correlation coefficient shown by the crop in Division 2 over that in Division 1, is thought to be due the difference in surface coverage.

Our observation started when the crop in Division 1 was 3 month old, while that in Division 2 was 4 month old. The crop in Division 2 would therefore be always ahead developing its canopy into a more better coverage. Thus on all occasions the surface in Division 2 was more homogenous to reflect the solar radiation then did the crop in Division 1. It should be recalled that NDVI was intended to monitor the coverage of the surface.

Regressing BR1 (Band Ratio 1) on the soil moisture and leaf water content resulted in the following Table 3.

Table 3. Regression of BR1 (Y) on soil moisture or leaf water content

Division	Regression Equation	r	Status of Y
<u>Soil Moisture</u>			
(I)	$Y = - 2.05 + 29.9 X - 68 X^2 **$	.83	Lag = 0 day
	$Y = - 2.26 + 33.9 X - 88 X^2 **$	.90	= 1 day
	$Y = - 0.10 + .8 X + 40 X^2 **$	.85	= 2 days
(II)	$Y = 2.09 - 27.6 X + 125 X^2 **$	.84	Lag = 0 day
	$Y = 4.10 - 60.8 X + 261 X^2 **$	.87	= 1 day
	$Y = 3.89 - 59.4 X - 266 X^2 **$	.83	= 2 days
<u>Leaf water content</u>			
(I)	$Y = - 2.21 + 4.13 X **$	.83	Lag = 0 day
	$Y = - 2.19 + 4.10 X **$	.78	= 1 day
	$Y = - 1.53 + 3.17 X **$	.57	= 2 days
(II)	$Y = - 3.94 + 7.04 X **$	.79	Lag = 0 day
	$Y = -2.68 + 5.10 X *$	.69	= 1 day
	$Y = - 3.15 + 5.90 X **$	.77	= 2 days

Table 3 shows that Band Ratio 1 gives better representation of the soil moisture condition than did NDVI (Table 1). Also all lags show better correlation which are highly significant.

The similar tendency shown by the data in Table 1 through 3 suggests that surface characteristics are the determining factor here. Both division have sandy clay loam soil. However Division 1 has more clay and is less sandy than the soil in Division 2. Division 1 also has more organic material than Division 2. Therefore, the soil in Division 1 could retain more water compared to the soil in Division 2. This is evident from Figures 1 and 2. The crop in Division 1 would therefore be more turgid and thus reflect better than the crop in Division 2.

Here again, the use of satellite data with one day lag would give better estimate of the soil moisture, while the leaf water content could be better estimated using real time data.

Results of the regression of Band Ratio 2 on soil moisture and leaf water content are presented in Table 4. The table shows similar feature as that of NDVI and Band Ratio 1. As expected soil moisture is better represented when using satellite data one day after its observations



while for the leaf water content, better result is obtained when data of the same day are used (Table 4).

Table 4. Regression of BR2 (Y) of soil moisture and leaf water content

Division	Regression Equation	r	Status of Y
<u>Soil Moisture</u>			
(I)	$Y = 14.0 - 166X + 533X^2$ **	.84	Lag = 0 day
	$Y = 11.7 - 129X + 393X^2$ **	.85	= 1 day
	$Y = 9.8 - 106X + 314X^2$ **	.81	= 2 days
(II)	$Y = 1.04 - 239X - 135X^2$ **	.73	Lag = 0 day
	$Y = 4.09 - 24.4X - 38X^2$ **	.81	= 1 day
	$Y = 1.41 + 13.3X - 146X^2$ **	.72	= 2 days
<u>Leaf water content</u>			
(I)	$Y = 12.5 - 16.7X$ **	.78	Lag = 0 day
	$Y = 10.0 - 13.0X$ **	.67	= 1 day
	$Y = 10.2 - 13.3X$ **	.69	= 2 days
(II)	$Y = 7.89 - 9.13X$ **	.78	Lag = 0 day
	$Y = 7.47 - 8.55X$ **	.69	= 1 day
	$Y = 5.99 - 5.94X$	.48	= 2 days

Comparing the three measures under evaluation, Band Ratio 1 would be the best for estimation and monitoring of soil moisture. Its one day lag correlation coefficients are the highest among the three measures. Aside from this it also displays consistency considering the range of the correlation coefficients obtained between the divisions.

On the other hand the results of the regression of real time satellite data on the leaf water content are ambiguous. Band Ratio 1 has higher correlation coefficient, however Band Ratio 2 shows more consistency.

The identical correlation coefficients in Division 1 and Division 2 for no lag relation, suggest that both divisions reflect equally well in the two bands, or nearly so. This however conflicts with what has been obtained with NDVI or with Band Ratio 1. The soil moisture and the leaf water content data also do not support this argument (see Baharsjah et al., 1983). The consistency displayed by Band Ratio 2 should therefore be ignored.

The correlation coefficient obtained here for the three measures are sufficiently convincing to allow the use of satellite data to monitor diurnal changes in soil moisture. The estimate of ETA could therefore be accomplished for any area given that it is cloud-free.

### CONCLUSIONS

Soil moisture condition relates strongly to the leaf water content one day after its observation. Accordingly soil moisture conditions are better observed by satellite with a time lag of one day. In other words satellite data on any day reflects the soil moisture condition of the previous day.

Soil moisture as well as leaf water content of the sugarcane crop could best be monitored with Band Ratio 1 of the NOAA satellite. As it was intended, NDVI could serve to monitor the area planted and harvested.

### REFERENCES

- Baharsjah, J.S., M.E. Manan, P.M. Sitaniapessy, I. Santosa and H. Subarsono, 1983. Penelitian radiasi netto/kofisien pemantulan areal tanaman pada beberapa tingkat ketersediaan air tanah. Lembaga Penelitian IPB.
- Dale, F.F. and R.H. Shaw, 1965. Effect on corn yields of moisture stress and stands at two fertility levels. *Agronomy Jour.* 57 : 475 - 479
- Hapip, A.S., A. Hidayat dan Sutrisno S., 1988. Pengamatan keadaan hutan di Kalimantan dengan satelit selama musim kemarau. Proc. Simposium II Agrometeorologi. PERHIMPI.
- LAPAN, 1987. Unpublished data.
- Shaw, R.H., 1974. A weighted moisture stress index for corn in Iowa. *Iowa State Jour. Research* 49 : 101 - 114
- \_\_\_\_\_, 1978. Modelling crop yield using climatic data, in : *Agrometeorological Research Needs of the Semi Arid Tropics.* R.H. Shaw *et al.* eds ICRISAT : 154 - 161



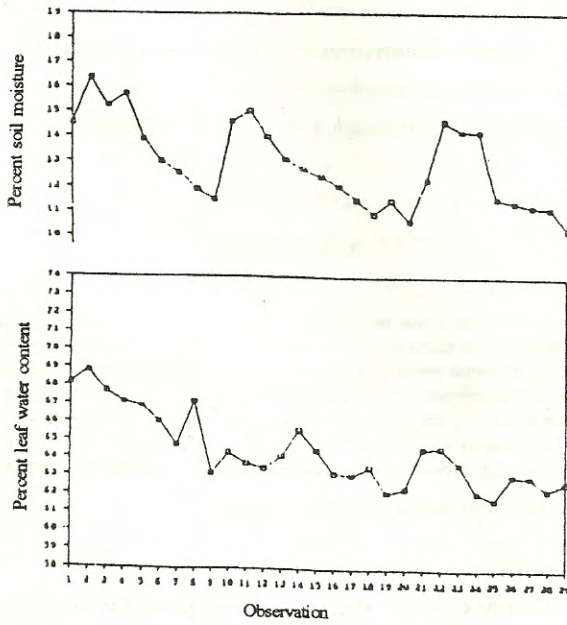


Fig. 1. Leaf water content of the crop and soil moisture in Division 1.

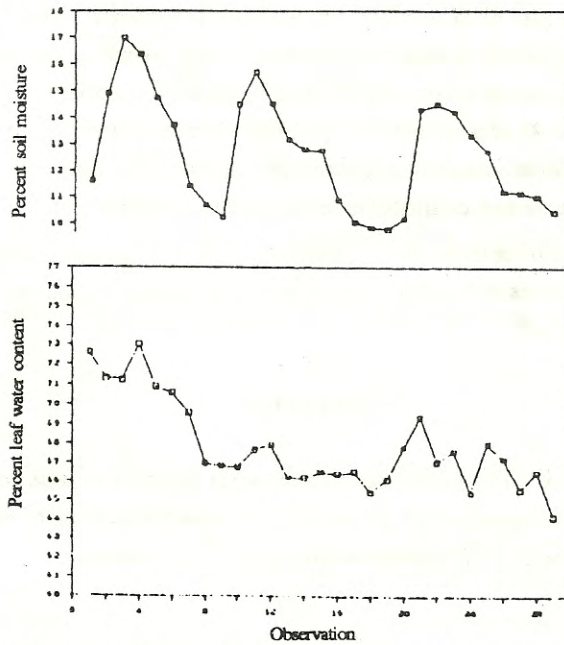


Fig. 2. Leaf water content of the crop and soil moisture in Division 2.