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Estimating evapotranspiration of mustard and chickpea using remote sensing parameters

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ABSTRACT

This paper presents an approach for estimating evapotranspiration (ET) in mustard and chickpea crops from remotely sensed data using the concept of Vegetation Index-Temperature Trapezoid (VITT) of Moran *et al* (1994). Field experiments were conducted with three irrigation treatments for obtaining a wide range of biophysical parameters and hence the ET values. From the spectral reflectance and canopy air temperature difference (CATD) measurements, ET was estimated and the water availability index (WI) was calculated and related to the biophysical parameters of the two crops. Results showed that the estimated ET values were in good agreement with the values obtained by modified Penman method using crop coefficients, thereby indicating that remote sensing data can provide a practical means of estimating crop ET (ET_a) and there from the soil water status.

Keywords : Evapotranspiration, vegetation index, surface temperature, water availability index, remote sensing.

Remote sensing has been widely used for large area estimation of mass and energy fluxes of which evapotranspiration is an important parameter in studying the water and energy balances on the earth's surface. Understanding the distribution of surface moisture and evapotranspiration (ET) is a key factor in successful application of water balance models to agricultural water management. The objectives of this study are to simplify the crop ET estimation by incorporating remote sensing parameters such as surface temperature, NDVI, for mapping its spatial distribution.

Earlier studies on canopy surface temperature (T_s) found that there exists a negative correlation between T_s and vegetation index, such as normalized difference vegetation index (NDVI) of an actively transpiring vegetation (Hope *et al.*, 1992; Nemani and Running, 1989, and Moran *et al.*, 1994). It is found that T_s and NDVI are indicators of evaporative cooling by plant transpiration. Based on this hypothesis, Moran *et al.* (1994) have proposed the concept of VITT. This concept combines the NDVI and difference between canopy temperature (T_c) and air temperature (T_a), (CATD), to arrive at the crop water availability index (WI) for partially covered vegetation fields. Through the WI, one can estimate the ET of the crop, when the potential value of evapotranspiration is known from any other method (Xihua *et al.*, 1997). Thus the present paper describes a method of ET estimations from partially covered crop fields through remote sensing data like CATD, NDVI, by determining the WI.

VITT Concept

The VITT concept described here has been adopted from Xihua *et al.*, 1997. This approach is based on the hypothesis that a trapezoidal shape would result, while plotting measured CATD values against canopy cover (V_c). The vertices of the trapezoid would correspond to: (1) well-watered full-cover vegetation; (2) water-stressed full-cover vegetation; (3) saturated bare soil; and (4) dry bare soil (Fig. 1).

Using physical energy balance equations described by Jackson *et al.* (1981) and later by Moran *et al.* (1994), it is possible to compute the values of four vertices of the trapezoid for a specific time and crop. In Fig. 1, V_c can be substituted with a vegetation index computed from remotely-sensed index like NDVI as it is an established fact that there exists a good linear correlation between NDVI and the V_c (Xihua *et al.*, 1997; Hope and Mcdowell, 1992; Jackson, 1985; Nemani and Running, 1989). Therefore, it is possible to compute the maximum and minimum CATD values using vegetation index NDVI. The following equations were suggested by Moran *et al.*, (1994)

$$CATD_{max} = a_0 + a_1 \, NDVI \quad \text{............(1)}$$

$$CATD_{min} = b_0 + b_1 \, NDVI \quad \text{............(2)}$$

where a_0 and a_1 are the offset (° C) and slope of the line connecting points 2 and 4, and b_0 and b_1 are the offset (°C) and slope of the line connecting points 1 and 3 in Fig. 1. The water availability index (WI) is then computed using the relationship given by Moran *et al.*, (1994).

$$WI = \frac{CATD_{max} - CATD_r}{CATD_{max} + CATD_{min}} = \frac{ET_a}{ET_p} \quad \text{........(3)}$$

where ET_a and ET_p are actual and potential ET values of the crop; $CATD_r$ is the value of canopy air temperature difference on that particular day.

MATERIALS AND METHODS

Field experiments were conducted in *rabi* season of 1998-99 and 1999-2000 with mustard and chickpea crops in the farm area of Indian Agricultural Research Institute, New Delhi. The fields were sown in 6 x 5 m² plots adopting RBD design with three replicates. The crops were given pre-sowing irrigation with recommended fertilizer dose and were maintained in such a way that the fields were without weeds. Three treatments of irrigation T_1, T_2 and T_3 were given.

T_1 – One irrigation (30 DAS),

T_2 – Two irrigation (30 and 65 DAS)

T_3 - Three irrigation (30, 65 and 85 DAS)

Canopy surface reflectance was measured using a Spectro-radiometer (LI-1800) operating in the visible and near infrared bands (300-1100 nm); radiance

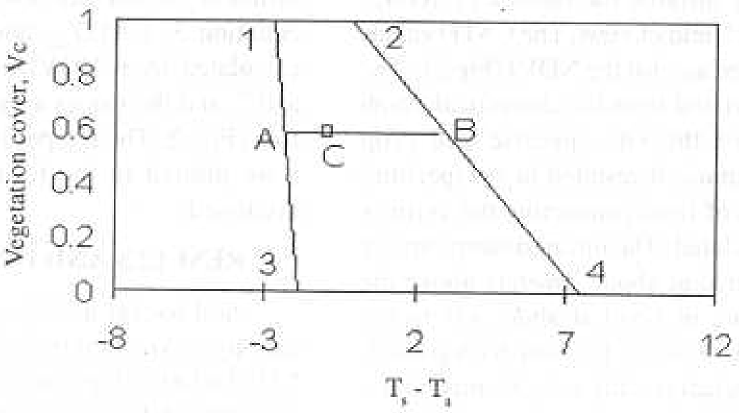

Fig. 1 : The trapezoidal shape from the relation between T_s-T_a and V_c (Theoretical) (Adopted from Xihua *et al.*, 1997.)

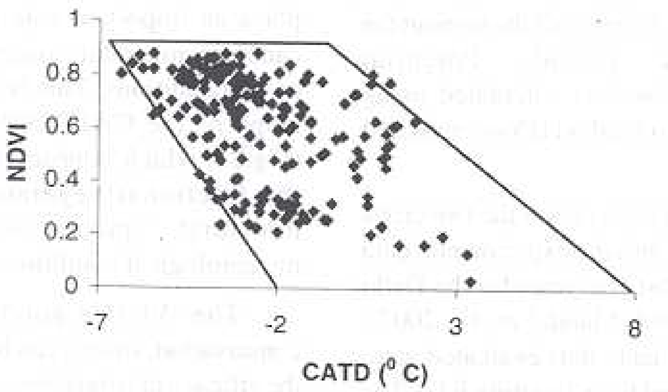

Fig. 2 : The trapezoidal shape from the relation between CATD and NDVI (From experimental data)

data was obtained on cloud free days once in a week, throughout the crop growth period. The reflectance of the target is calculated as the ratio of the radiance measured over each target to irradiance measured over a calibrated reflectance panel. This reflectance in the bands 600 – 700 nm (R_1) and 800-1100 nm (R_2) data is converted to vegetation index NDVI by the formula

$$NDVI = \frac{R_2 - R_1}{R_2 + R_1}$$

The surface temperature and CATD were measured simultaneously on all the days using infrared thermometer (AG-42) having a 2° field of view. The CATD values were plotted against the NDVI (Fig.2). The slopes deviated from the theoretical graph because of the site-specific and crop specific nature. It resulted in a trapezium; the slopes of lines connecting the vertices were calculated. The infrared thermometer was mounted at about 2 meters above the ground, and inclined at about 45° to the horizontal to avoid the soil background. Meteorological conditions (air temperature, humidity, wind speed, and net radiation) were taken from the observatory located near the field. Collateral information of the crops, like leaf area and biomass were collected at weekly intervals throughout the crop growth period. Potential evapotranspiration was calculated using modified Penman method (Doorenbos and Pruitt, 1977).

Crop coefficients for the two crops were evaluated from the experimental data collected over past few years for the Delhi region (Rao, 1992, Mandal *et al.*, 2002). The crop coefficients thus evaluated were subsequently used for estimating ET_a. The following equations were developed to compute the crop coefficients as a function of DAS (days after sowing) in both crops of mustard and chickpea.

Mustard crop coefficient $= 4 \times 10^{-8} \times DAS^4 - 10^{-5} \times DAS^3 + 0.0006 \times DAS^2 + 0.0088 \times DAS + 0.1799$

Chickpea crop coefficient $= 3 \times 10^{-7} \times DAS^3 - 0.002 \times DAS^2 + 0.0303 \times DAS - 0.1544$

Finally WI values of the two crops at different growth stages were calculated by equation 3. $CATD_{max}$ and $CATD_{min}$ were calculated from NDVI using equations 1 and 2, and the slopes a_0, a_1, b_0, b_1 obtained from Fig. 2. The temporal variation of WI were plotted in the form of graphs and discussed.

RESULTS AND DISCUSSION

Soil background temperature and the canopy cover determine the CATD and NDVI relationships during early part of the crop period. It is known that the crops are cooler than the soil surface temperature during the day compared to night (Xihua *et al.*, 1997). Thus soil surface temperature plays an important role in the measured canopy temperature under partial canopy cover conditions. This is evident from the slope of the CATD/NDVI relationship (Fig.2.), which is primarily controlled by the fractional vegetation cover, soil moisture status and prevailing meteorological conditions.

The WI is a good tool for water conservation, since it can be used to monitor the efficacy of irrigations and identify fields where evaporative water loss is more. The graphs of water availability index WI, which was computed with equation 3, for both the crops are given in Fig. 3 for the two years along with rainfall. Lower values of WI were observed in T_1 treatment compared to the others which resulted in less uniform growth because of only one irrigation. Although there was considerable rainfall (46.7 cm), during the second season, it did not reflect in increase of WI compared

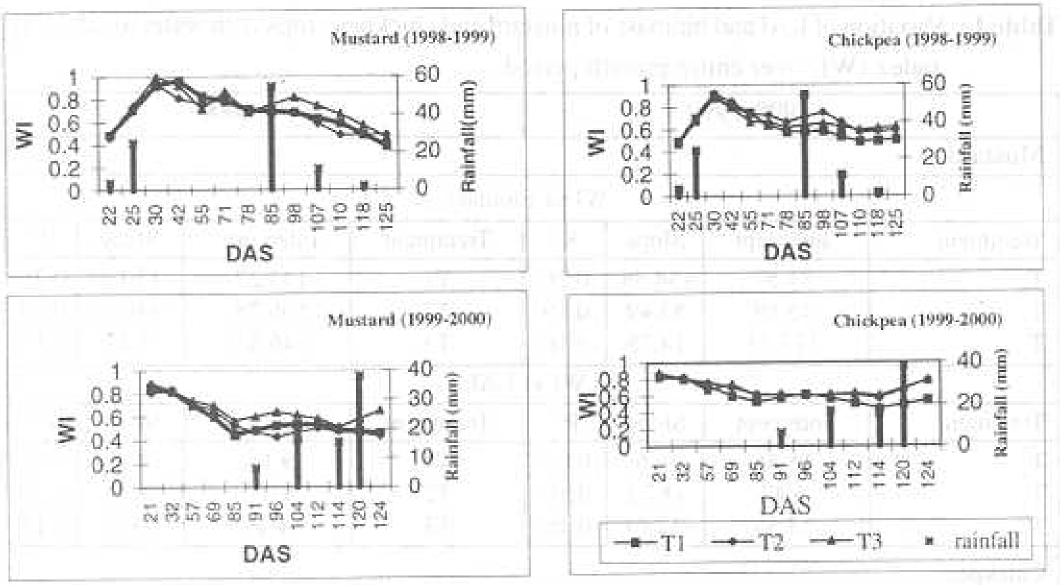

Fig. 3 : Variation of water availability index (WI) and rainfall in mustard and chickpea crops

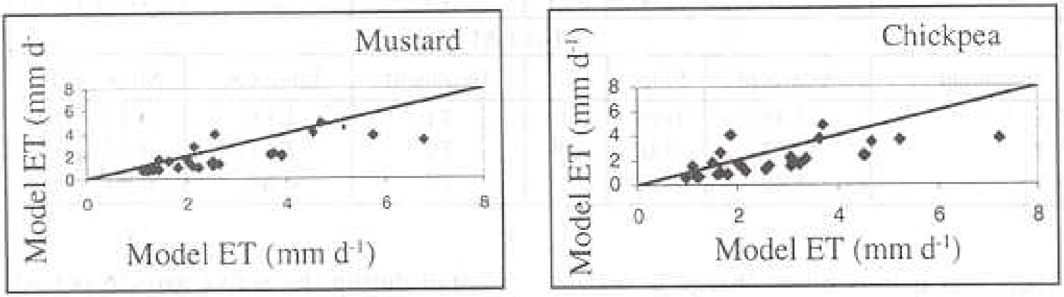

Fig. 4 : Variation of actual to model ET of mustard and chickpea

to first season in both the crops as it occurred after the active crop growth period. The WI of both crops did not show much difference in all treatments in the later part of the growing seasons.

Irrigation application resulted in more branching in case of chickpea and more pods in mustard plots. Higher water availability leads to increased crop growth and hence in crop ET (Moran *et al.*, 1994).

Table 1 : Variation of LAI and biomass of mustard and chickpea crops with water availability index (WI) over entire growth period.

1998-1999				1999-2000			
Mustard							
WI vs Biomass							
Treatment	Intercept	Slope	R^2	Treatment	Intercept	Slope	R^2
T_1	81.57	-54.38	0.26	T1	143.27	-150.95	0.76
T_2	45.68	55.49	0.19	T2	506.78	-480.78	0.20
T_3	173.15	14.25	0.16	T3	246.03	3.47	0.17
WI vs LAI							
Treatment	Intercept	Slope	R^2	Treatment	Intercept	Slope	R^2
T_1	15.86	-16.65	0.09	T1	5.11	-4.26	0.88
T_2	6.47	-3.72	0.10	T2	5.05	-0.78	0.23
T_3	13.54	-12.61	0.16	T3	-4.43	69.31	0.18
Chickpea							
WI vs Biomass							
Treatment	Intercept	Slope	R^2	Treatment	Intercept	Slope	R^2
T_1	56.24	-62.94	0.72	T1	68.20	-70.80	0.74
T_2	67.01	-68.61	0.19	T2	153.71	-129.76	0.21
T_3	25.33	22.42	0.21	T3	-12.47	144.71	0.16
WI vs LAI							
Treatment	Intercept	Slope	R^2	Treatment	Intercept	Slope	R^2
T_1	1.38	0.95	0.12	T1	1.13	-1.11	0.29
T_2	3.67	-3.01	0.09	T2	2.33	-1.83	0.08
T_3	3.48	-2.77	0.11	T3	0.68	0.90	0.06

There was quite a bit of change in water availability in both the years due to variations in total rainfall during the two years, 114.9 cm in 1998-1999 and 79.7 cm in 1999-2000. The water availability index (WI) in 1998-1999, gave poor correlation with the LAI and biomass in all treatments over the entire crop season. This is probably due to changes in crop geometry and leaf area development occurring because of rainfall during the active growth period. Whereas in 1999-2000 the same index gave good correlation with LAI and biomass (Table 1) of mustard in T_1 treatment, because of uniform growth upto maximum leaf area development and the absence of rains during the active growth period. In T_2 and T_3 treatments the irrigation enhanced the crop growth rate but resulted in poor correlation in LAI and biomass with WI

Table 2 : Relation between cumulative WI (CWI) and biomass (g plant^{-1}) and LAI of mustard and chickpea

Regression equation	R^2
Mustard	
Biomass = $-027x(CWI)^3+0.2195 \times (CWI)^2-2.3445 \times (CWI) + 6.5306$	0.88
LAI = $-0.0002 \times (CWI)^3+0.0047x\ CWI)^2+0.1578 \times (CWI) - 0.7470$	0.62
Chickpea	
Biomass = $0.0004 \times (CWI)^3+0.0563 \times (CWI)^2-1.8693 \times (CWI) +16.0300$	0.57
LAI= $-0.0005 \times (CWI)^3+0.0033 \times (CWI)^2-0.1005 \times (CWI) +0.8351$	0.56

(Table 1). In case of chickpea in both years there was good correlation (Table 1) between the WI and biomass in the treatment T_1. Biomass with WI in other treatments (T_2 and T_3) resulted in no significant correlation, because of the tricky nature of chickpea development and its sensitivity to rain/irrigation. Chickpea LAI and WI gave no correlation in both years as rains and irrigation played an important role in leaf area / branch development. However, the biomass and LAI have shown a good correlation with WI up to senescence stage in both crops and in both years (R^2=0.89 and 0.78 in mustard, R^2=0.91 and 0.86 in chickpea for 1998-1999 and 1999-2000 respectively). It is felt that if cumulative water availability index (CWI) is calculated similar to GDD (growing degree days) then CWI correlated well with LAI and biomass of these crops. The pooled data for both years were used and the relations got for mustard and chickpea are presented in Table 2.

The crop ET values obtained by this method are compared (Fig. 4) with those obtained by modified Penman method (Doorenbos and Pruitt, 1977) using the derived crop coefficients. The model values obtained by this method were observed to under estimate to the extent of 15% . However, they are within the acceptable accuracy in evaluating ET of these two crops particularly upto crop ET of 5 mm d^{-1}. The results show that the remote sensing data can provide a practical means for estimating ET of mustard and chickpea and also for monitoring the soil water status through WI.

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