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Cross calibration of leaf area index measurements by canopy analyzer and line quantum sensor over wheat crop*

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ABSTRACT

Studies were carried out at 28 locations in farmers' fields of wheat crop during *rabi* season of 2000-2001 within a stretch of 15 km surrounding Chharodi Agricultural Research Farm of Gujarat Agricultural University to measure and cross calibrate green leaf area index (LAI) at maximum tillering and grain filling stages of wheat, separately by line quantum sensor (SS-1 type) and field calibrated canopy analyzer (LAI-2000). Both the pooled and individual datasets for different crop growth stages were utilized for cross calibration of line quantum sensor (SS-1 type) with respect to canopy analyzer. Leaf area index values were found to range from 0.9 to 6.0 at different growth stages of wheat. Linear regression relations with high R^2 values were found to exist in case of pooled dataset ($Y = 0.876X + 0.357$) as well as individual datasets.

Key words: Leaf area index, plant canopy analyzer, line quantum sensor

Leaf area index (LAI), which is defined as one sided total green leaf area of plant per unit ground area, is useful input for studying crop growth, radiation interception, water use and use efficiency. It also acts as one of the important input parameters for crop growth simulation models. In recent years, several indirect methods of LAI measurement have been developed that relate the radiative environment below and above the crop canopy to leaf area by use of radiation transfer models (Ross, 1981; Norman and Campbell, 1989). Among the direct methods, the higher accuracy of measurements of LAI of different crops is obtained by both line quantum sensor (Lang, 1987 and Lang and Yueqin, 1986) and plant canopy analyzer (Welles and Norman, 1991 and Hicks and Lascano, 1995). Both the instruments use the principle of light interception in a different way. Since the spatial application of crop simulation models and its coupling with remote sensing and GIS is gaining importance, the retrieval and ground validation of crop biophysical parameters such as LAI from satellite images is of urgent need of the research in recent future.

Keeping the need of non-destructive LAI measurements over farmers' field in mind, the present study was aimed to cross

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calibrate line quantum sensor with respect to calibrated plant canopy analyzer for LAI over wheat crop.

MATERIAL AND METHODS

Field measurements were carried out on LAI by both line quantum sensor (Sun Scan SS – 1 type) and calibrated LICOR plant canopy analyzer (LAI 2000) in different wheat fields surrounding agricultural research farm of Gujarat Agricultural University at Chharodi during *rabi* season of 2000 – 2001. The data on LAI were collected with both the instruments at different phonological stages of wheat on 13/12/2000, 29/12/2000, 23/1/2001 and 14/2/2001. The data on LAI were collected from the four corner points of each selected field and ultimately the mean values were worked out from the four measurements. While taking the measurements, the sensor of Sun Scan SS –1 type was placed across the wheat rows horizontally, but LAI was measured by plant canopy analyzer (LAI 2000) by placing the sensor once above the canopy followed by placing it at four different points below the canopy diagonally across the rows.

Line Quantum Sensor (Sunscan SS1-UM-1.05)

According to Beer's law, for a uniform, infinitely and randomly distributed canopy of completely absorbing leaves,

$$I = I_0 EXP(-k.L) \quad .....(1)$$

where,

k= canopy extinction coefficient depending on leaf angle distribution and direction of the beam

L= leaf area index

I = transmitted radiation

I_0= incident beam radiation

Campbell (1995) has developed ellipsoidal leaf angle distribution (LAD) equations assuming k of leaves distributed in the same proportion and orientation as the surface of ellipsoid of revolution , symmetrical about a vertical axis.

$$k(x,\theta) = \sqrt{(x^2+\tan^2\theta)}/(x+1.702(x+1.12)^{-0.708}) \quad .....(2)$$

where,

x = ellipsoidal leaf angle distribution (ELADP) parameter = b/a ; a = semi vertical axis, b = semi horizontal axis

θ = zenith angle of direct beam

Direct transmitted fraction τ_{dir}

$$= EXP(-k(x,\theta).L) \quad .....(3)$$

Direct fraction rarely exceeds 80% of the total incident radiation. Diffuse light also penetrates canopy but does not obey Beer's law. For diffuse radiation, the radiance of a strip around the sky at an angle θ is

$$R = \pi 2 \, Sin\theta.d\theta \quad ..... (4)$$

The irradiance on a horizontal surface due to that strip is given by

$$I_0 = 2\pi Sin\theta Cos\theta d\theta \quad ..... (5)$$

Total transmitted radiation,

$$I = \int_0^{\pi/2} 2\pi Sin\theta Cos\theta EXP(-k(x,\theta).L)d\theta \quad ..... (6)$$

The integral was evaluated numerically over the range of x = 0-1000 and L = 0-10

Most of the crops have ELADP in the range of 0.5 to 2.0.

ELADP = 1.0 for spherical leaf angle distribution

= 1024 for broad flat ellipsoid when leaves are horizontal

= 0.0 for tall thin ellipsoid when leaves are vertical

Plant canopy analyzer (LAI 2000)

Measurement of LAI using LAI-2000 plant canopy analyzer is based on "fisheye" measurement of light interception by measuring gap fraction. If the foliage elements are randomly distributed in the region through which the ray passes and compared to overall canopy dimensions

Probability of non-interception

$$(T(\theta,\varphi)) = EXP(-G(\theta,\varphi)\mu\ S(\theta,\varphi))$$

where,

$G(\theta,\varphi)$ = fraction of foliage projected toward direction

θ = zenith angle of ray

φ = azimuth angle of ray

μ = foliage density (m^2/foliage cubic meter canopy)

$S(\theta,\varphi)$ = path length (m)

Since LAI-2000's optical sensor averages over azimuth,

$$G(\theta)_{\mu} = -\ln(T(\theta))/S(\theta) = K(\theta) \quad .....(7)$$

$K(\theta)$ = contact frequency = av. No. of contacts / unit length of travel that a probe would make passing through the canopy at zenith angle (θ).

$$\mu = 2\int_0^{\pi/2} -(\ln(T(\theta))/S(\theta))\mathrm{Sin}(\theta)d\theta \quad .....(8)$$

For full homogeneous canopy $L = \mu Z$,

where Z = canopy height

L = leaf area index

So,

$$L = 2\int_0^{\pi/2} -(\ln T(\theta))\mathrm{Cos}\theta\mathrm{Sin}\theta d$$

Because canopy height Z cancels out in the above equations,

$$S(\theta) = 1/\mathrm{Cos}\theta$$

$$L \text{ or } \mu = 2\sum_{i=1}^{5} -\ln(Ti)Wi/Si$$

T_i = are five gap fractions (expressed as the ratio of below-canopy measurements to above canopy measurements), and W_i = are the $\mathrm{Sin}\theta d\theta$ values, which are 0.034, 0.104, 0.160, 0.218 and 0.484 for the five angles of view of the LAI – 2000 sensor, when normalized to sum to 1.0. The S_i values normally $1/\mathrm{Cos}\theta$ or 1.008, 1.087, 1.270, 1.662 and 2.670 are stored in the control box and are available to the user.

RESULTS AND DISCUSSION

Green LAI was found to range from 0.9 to 6.0 from vegetative to reproductive stages over different wheat fields. The linear plot of of pooled data of LAI measured by line quantum sensor (SS – 1 type) and plant canopy analyzer (LAI 2000) at different stages of wheat crop is presented in Fig. 1. Regression analysis between the measurements by two different instruments was carried out for

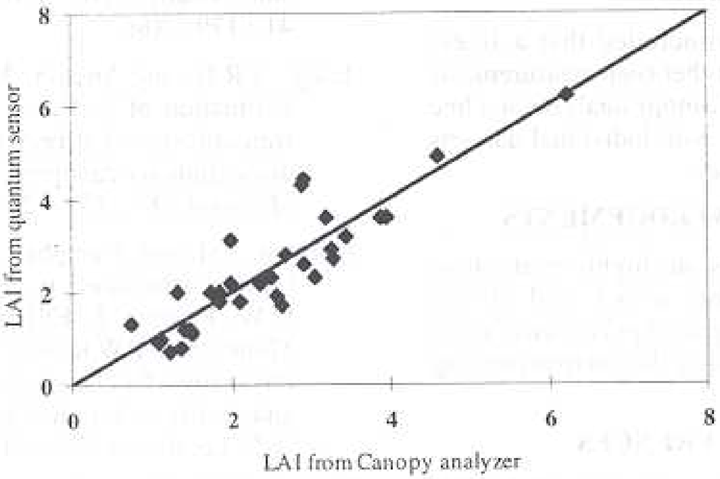

Fig. 1 : Calibration plot of LAI measured from quantum sensor and canopy analyzer

cross calibration individually at (i) vegetatitve stage i.e. at maximum tillering stage and (ii) reproductive stage i.e. grain filling stage and with pooled datasets.

The linear relationship was found to exist for vegetative stage as well as reproductive stage and for pooled dataset. The regression equations are presented below:

For maximum tillering stage,

$Y = 0.834X + 0.467$

$R^2 = 0.76$; $SE = \pm 0.524$ ..... (9)

Where,

Y = LAI measured by line quantum sensor

X = LAI measured by calibrated plant canopy analyzer

N = no. of observations

For grain filling stage,

$Y = 0.748X + 0.747$ $N = 13$

$R^2 = 0.75$; $SE = \pm 0.610$ ..... (10)

For pooled dataset,

$Y = 0.876X + 0.357$ $N = 32$

$R^2 = 0.82$; $SE = \pm 0.555$ ..... (11)

Relatively higher correlation existed with pooled dataset as compared to datasets at individual growth stages.

Welles and Norman (1991) reported that the error of LAI measurements by plant canopy analyzer (PCA) was generally less than 15%. Variations in sky brightness patterns caused variations in LAI estimates in winter wheat of less than 10%. The PCA underestimated LAI by ^{3}20% when measurements were made on canopies of wilted cotton crop due to water stress (Hicks and Lascano, 1995). The above observations on measurement errors supported the magnitude of errors of correlation between the measurements of LAI *in situ* by line quantum sensor and plant canopy analyzer

It can be concluded that a linear relationship exists between measurements of LAI by plant canopy analyzer and line quantum sensor with individual datasets and pooled dataset.

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