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FULL LENGTH ARTICLE

Using models for estimation of leaf area index in *Cucurbita pepo* L.

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Abstract In order to find plant growth characteristic relationships with leaf area index in Pumpkin (*Cucurbita pepo* L.), an experiment was conducted based on randomized complete block design with three replications. Three planting dates (Apr. 20, May 21 and Jun. 21) performed at the research field of Abooreihan Campus, the University of Tehran, Pakdasht, Tehran, Iran, in 2009–2010 cropping season. Sampling was performed during the whole growing season and leaf area (LA), leaf no. per plant, leaf dry weight (LDW), leaf fresh weight (LFW), node no. per main stem and plant height, were measured. The aim of this study was to collect and evaluate nonlinear regression models in the plant growth characteristic studies (exponential, Gaussian, linear, quadratic, symmetric, sigmoid). Root Mean Square Error (RMSE), the standard error of the estimate (SE) and coefficient of determination (R^2) were used to find the appropriate model(s). The result showed that, the linear model predicted significant relationships between LAI and LA (R^2 = 90), LAI and leaf no. per plant (R^2 = 90), LAI and node no. per main stem (R^2 = 90), LAI and LDW (R^2 = 98) and LAI and LFW (R^2 = 98). These result showed that the linear model can be used for estimation of LAI Pumpkin, especially where there is no LAI-meter available.

1. Introduction

Cucurbita pepo is an important vegetable food crop with medicinal value, including treatment for benign prostatic hyperplasia and leprosy (Hamissou et al., 2013), that is consumed either raw in salads or cooked in soups (Atashi et al., 2015). The genus Cucurbita L. (pumpkins and squash) is native to the Americas where there is evidence of their culture more than 10,000 years ago (Smith et al., 1997), according to

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archaeological recordings, where *Cucurbita pepo* L. appears to be one of the first domesticated species (Aliu et al., 2011). The content of vitamin E in medicinal pumpkin seeds is very high (Murkovic et al., 1996). The oil content of the medicinal pumpkin seed varies from 42% to 54% and the composition of fatty acids is dependent on several factors (variety, area in which the plants are grown, climate, state of ripeness). The dominant fatty acids comprise palmitic, stearic acid, oleic acid and linoleic acid (Murkovic et al., 2004). Plant growth and development are determined by several characteristics such as Leaf Area Index (LAI), Fresh and Dry weight, Node no. and plant height. The LAI, defined as the ratio of the leaf area of a plant population to the ground area it occupies, is an important index of the canopy. It expresses the effect of the emergence and expansion of leaves, and interaction with the input of CO_2 and energy flow, and directly affects the interception of solar radiation, photosynthesis, accumulation of biomass, transpiration and gas exchange in the crop canopies (Jonckheere et al., 2004; Kandiannan et al., 2009).

LAI is an excellent indicator of crop development and health, and is used as an input variable for crop growth and yield forecasting models. Various ground methods are used to measure LAI including hemispherical photography (Demarez et al., 2008; Tang et al., 2014), optical sensors with the LAI-2000/2200 (Tang et al., 2014) and terrestrial Light Detection and Ranging (LIDAR) scanning (Jensen et al., 2008; Riaño et al., 2004). But we can predict LAI with using relationship between LAI and the other vegetable characteristics.

The regression models, those classified as nonlinear are useful for describing growth over time as they use biological interpretation parameters that make analyses easier. According to Seber and Wild (1989) and Bates and Watts (2007) nonlinear models are generally adopted when it is suspected that the relationship between the response variable and the predictors follows a particular function. The application of nonlinear growth models can be found in a range of studies in the literature in various areas. In the agricultural sciences, the studies in this area evaluate the entire cycle of a specified species or growth model according to the application of different crop management techniques or comparison between genotypes, as can be seen in Hernández et al. (2007), Barrera et al. (2008) Tarara et al. (2009), Akpo et al. (2014) and Carson et al. (2014). The purpose of this study was determination of the best model for prediction of LAI.

2. Material and methods

In order to find plant growth characteristic relationships with leaf area index in Pumpkin (*Cucurbita pepo* L.), an experiment was conducted based on randomized complete block design with three replications. Three planting dates (Apr. 20, May 21 and Jun. 21) performed in 2009–2010 at the research field of Abooreihan Campus, the University of Tehran. Abooreihan Campus was located in Pakdasht region at 35°28′N, 44°51′E and 1003 m above sea level, with an arid climate (9 hot and dry summers and mild winters). Long-term average prediction of the region is 170 mm. The soil was classified as loamy soil texture.

Based on soil chemical analysis, the fertilizer amount consumption was calculated on 100 kg of nitrogen per hectare using urea fertilizer (46% N) and 100 kg per hectare triple super phosphate fertilizers and potassium phosphate. Each experimental unit consisted of 6 planting rows with 7 m length. Seeds and row spacing were 30 and 150 cm respectively. Five seeds were planted in each hole and were thinned in 4-leaf seedlings stage. All weeds were removed manually during the experiment. Irrigation and pest and probable disease control operations were carried out in a way that no effects of drought, blight, and disease are found in pumpkin.

Samplings started two weeks after planting and continued every 14 days to the end of growing seasons. Three plants of each plot were harvested and leaf area (LA), leaf no. per plant, leaf dry weight (LDW), leaf fresh weight (LFW), node no. per main stem and plant height were evaluated.

Various models (Table 1) were used to describe the relationship between LAI and plant growth characteristics in different planting dates. Root mean square error (RMSE), the standard error of the estimate (SE) and the coefficient of determination R^2 were used for determination of the best model(s). Statistical analysis was performed using the Sigma Plot 11 program.

3. Results and discussion

Ranges, means and standard deviations are shown in Table 2 for plant growth characteristics in different planting dates. Among the planting dates, June allocated the lowest growth traits measured, probably due to the late cultivation of pumpkin and shortened growth period. The linear model 4 had a lowest RMSE and the highest R^2 compared to the other models, so this model was the best and used to estimate LAI (The results are not provided). In the best model, (a) is intercept and (b) is the slope of the line (Model factors).

Model fitting was done separately in each planting dates to describe the relationship between leaf area index and leaf no. per plant. The results showed no significant differences between planting dates. The model factor (b) varied from 1.37 to 1.50 (Table 3). Among the planting dates, May fitting

Table 1 Used Model for explanation of relationships between leaf area index and plant growth characteristic in pumpkin.

Number	Model category	Model name	Model
1	Exponential rise to max	Single, 2 parameter	$Y = a * (1 - \exp(-b * x))$
2	Peak	Gaussian, 3 parameter	$Y = a * \exp(-.5 * ((x - x0)/b)\hat{}2)$
3	Polynomial	Linear	$Y = y0 + a * x$
4	Polynomial	Linear	$\ln(Y) = a + b * \ln(x)$
5	Polynomial	Quadratic	$\ln(Y) = y0 + a * x + b * x^2$
6	Power	2 parameter	$Y = a * x^b$
7	Power	Symmetric, 4 parameter	$Y = y0 + a * \mathrm{abs}(x - x0)^b$
8	Sigmoidal	Sigmoid, 3 parameter	$Y = a/(1 + \exp(-(x - x0)/b))$

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Table 2 The value of mean, standard deviation and min-max leaf area index and plant growth characteristics in pumpkin.

Trait	Planting dates	Range	Standard deviation	Mean
Leaf area index				
	20 April	0.01–1.86	0.6709	0.7114
	21 May	0.01–2.48	0.7756	0.7736
	21 June	0.02–1.58	0.5504	0.5989
	Sum	0.01–2.48	0.6679	0.6979
Leaf no. Per plant				
	20 April	2.67–123.67	42.9552	45.6984
	21 May	4.50–135.67	39.589	46.5317
	21 June	5.67–100.33	26.869	32.9753
	Sum	2.67–135.67	37.4403	42.1731
Node no. Per main stem				
	20 April	1–45.33	15.7397	19.8095
	21 May	2–41	14.037	21.1111
	21 June	2.33–36.33	12.0174	19.1235
	Sum	1–45.33	13.8949	20.0593
Plant height (cm)				
	20 April	2.50–267	86.442	90.473
	21 May	4.50–202.17	68.5831	80.8952
	21 June	5–189	64.5764	75.9759
	Sum	2.50–267	70.8706	80.1011
Leaf fresh weight (g/m^2)				
	20 April	2.31–1081.44	321.2354	303.4214
	21 May	5.33–1139.33	307.6384	282.3287
	21 June	6.62–738.88	203.9678	197.7301
	Sum	2.31–1139.33	284.7138	264.3316
Leaf dry weight (g/m^2)				
	20 April	0.24–245.03	68.006	59.1787
	21 May	0.77–206.89	57.1837	52.9987
	21 June	1–132.03	36.8467	36.1203
	Sum	0.24–245.03	56.208	50.0982

model allocated the best prediction with the lowest RMSE (3.86) and SE (0.45) and highest R^2 (0.94).

Fig. 1 shows the relationship between the natural logarithm of observed and predicted LAI using the leaf no. per plant in different planting dates. There is a proper relationship between LAI and leaf no. per plant in different planting dates. Significant differences between different planting dates' model coefficients in the level of 5% did not exist (Table 3). The effective use of the leaf no. is emphasized in studies conducted by other researchers to estimate the leaf area of different plants. So Soltani et al. (2006) and Rahemi Karizaki et al. (2006) about peas and Madah Yazdi et al. (2008) about peas and wheat reported that leaf area in plant has a strong relationship with the node no. per main stem. Bakhshandeh et al. (2011) used a nonlinear two-pieced regression model to estimate leaf area from leaf no. per plant in wheat and predicted a good estimation of leaf area.

As seen in Table 3, the node no. per main stem indicates a good estimation of the LAI as well as the leaf no. in April and May planting dates. RMSE for different planting dates was variable between 3.42 and 6.02 and model estimation standard error from 0.45 to 0.64 (Table 3). Fig. 2 shows the relationship between the natural and estimated logarithm of leaf area index using the node no. per main stem on different planting dates. Sinclair (1984) for soybeans and Wahbi and Sinclair (2005) for wheat and barley used an exponential model to describe the leaf area via the node no. per main stem. Rahemi Karizaki et al. (2006) for peas and Madah Yazdi et al. (2008) for wheat and peas used the power model $y = ax^b$ and Hammer et al. (1993) for grain sorghum and Soltani et al. (2006) for peas used $y = x^b$ to estimate the leaf area via the node no. per main stem and reported proper estimation of the leaf area. Results of this experiment are consistent with the results of other researchers in terms of a proper estimation of leaf area index using the node no. per, but the model for the best estimation is different.

Relations of LAI with plant height have been brought for each planting date in Table 3. Coefficient of determination varied from 0.909 to 0.932 in different planting dates. Model coefficients showed no significant difference; therefore, this model can be used to fit the LAI using the plant height in all planting dates. Fig. 3 shows the relationship between the natural logarithm of estimated and observed LAI based on plant height in different planting dates. Bakhshandeh et al. (2011) reported the existence of a significant relationship between leaf area of wheat cultivars and plant height (R^2 = 0.91), with fitting the two pieced nonlinear model. Rahemi Karizaki et al. (2006) on peas, Akram-Ghaderi and Soltani (2012) on cotton and Lieth et al. (1986) on soybean used nonlinear models and Dwyer et al. (1992) on corn used third degree model to

Table 3 Coefficient of model *a* and *b* in *Y*)ln) = *a* + *b* * ln(*x*) between leaf area index and plant growth characteristics in pumpkin.

Trait	Planting dates	*N*	*a* ± se	*b* ± se	RMSE	SE	R^2
Leaf no. Per plant							
	20 April	21	−5.72 ± 0.35	1.42 ± 0.10	6.70	0.59	0.910
	21 May	21	−6.08 ± 0.29	1.50 ± 0.08	3.86	0.45	0.945
	21 June	18	−5.49 ± 0.51	1.37 ± 0.16	6.46	0.64	0.828
	Sum	60	−5.78 ± 0.21	1.44 ± 0.06	17.52	0.55	0.904
Node no. Per main stem							
	20 April	21	−4.34 ± 0.20	1.33 ± 0.07	3.93	0.45	0.947
	21 May	21	−5.66 ± 0.34	1.70 ± 0.12	6.02	0.56	0.915
	21 June	18	−5.49 ± 0.51	1.37 ± 0.16	3.42	0.64	0.828
	Sum	60	−4.92 ± 0.18	1.46 ± 0.06	18.05	0.56	0.901
Plant height (cm)							
	20 April	21	−5.16 ± 0.27	1.10 ± 0.07	5.13	0.52	0.931
	21 May	21	−6.30 ± 0.34	1.37 ± 0.08	4.81	0.50	0.932
	21 June	18	−5.40 ± 0.35	1.57 ± 0.12	4.79	0.46	0.909
	Sum	60	−5.57 ± 0.20	1.18 ± 0.05	17.02	0.54	0.907
Leaf fresh weight (g/m²)							
	20 April	21	−5.92 ± 0.12	1.01 ± 0.02	0.77	0.20	0.990
	21 May	21	−5.98 ± 0.07	1.05 ± 0.01	0.22	0.11	0.997
	21 June	18	−5.63 ± 0.27	0.97 ± 0.06	1.93	0.35	0.948
	Sum	60	−5.86 ± 0.09	1.01 ± 0.02	3.22	0.24	0.982
Leaf dry weight (g/m²)							
	20 April	21	−3.75 ± 0.08	0.90 ± 0.02	0.81	0.21	0.989
	21 May	21	−4.10 ± 0.04	1.01 ± 0.01	0.15	0.09	0.998
	21 June	18	−3.72 ± 0.14	0.91 ± 0.04	1.30	0.28	0.965
	Sum	60	−3.85 ± 0.05	0.94 ± 0.02	2.91	0.22	0.984

n: Number of Samplings, RMSE: Root Mean Square Error, SE: Standard Error of Estimate, R^2: Coefficient of Determination.

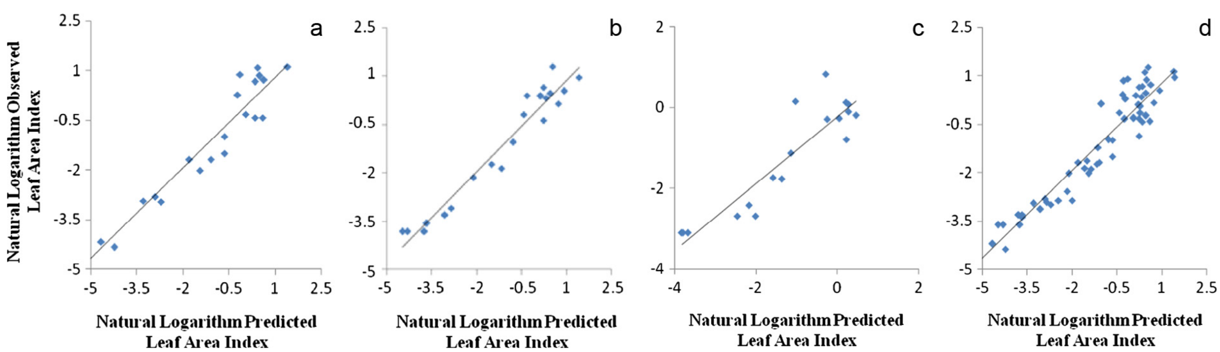

Figure 1 Relationship between observed and predicted Leaf Area Index and Leaf Number of pumpkins at 20 April (a), 21 May (b), 21 June (c) and all planting dates (d).

describe the relationship between leaf areas and plant height. Lieth et al. (1986) stated that in his research conducted on the soybean, plant height is not a good estimator for leaf area, which is not consistent with the results obtained in this study.

Relations between the leaf fresh weight and LAI for each plant date have been brought separately in Table 3. RMSE varied from 0.22 to 1.93 and standard error of the estimated models from 0.11 to 0.35. Coefficient of determination varied from 0.948 to 0.997 in different cultivations which indicates the proper relationship between LAI and leaf fresh weight (Table 2). Predicted and observed LAI fitting with fresh weight of leaf in different planting dates confirms the mentioned results (Fig. 4). None of the investigated sources didn't use leaf fresh weight to estimate leaf area because leaf fresh weight was influenced by temperature, irrigation, time of sampling, sampling interval and weighting the leaves immediately. But the results of this study showed that the leaf fresh weight had a strong relationship with LAI as well as leaf dry weight is able to predict LAI with fewer facilities (only needs scales, without the need for oven) and faster than the dry weight.

Using leaf dry weight to estimate LAI was successful as fresh weight of leaf so that the Coefficient of determination for models was variable from 0.965 to 0.998 (Table 3). It seems that one model can be used to estimate the LAI from leaf dry weight according to the model coefficients and standard errors of estimating models. Fig. 5 shows the appropriateness of leaf

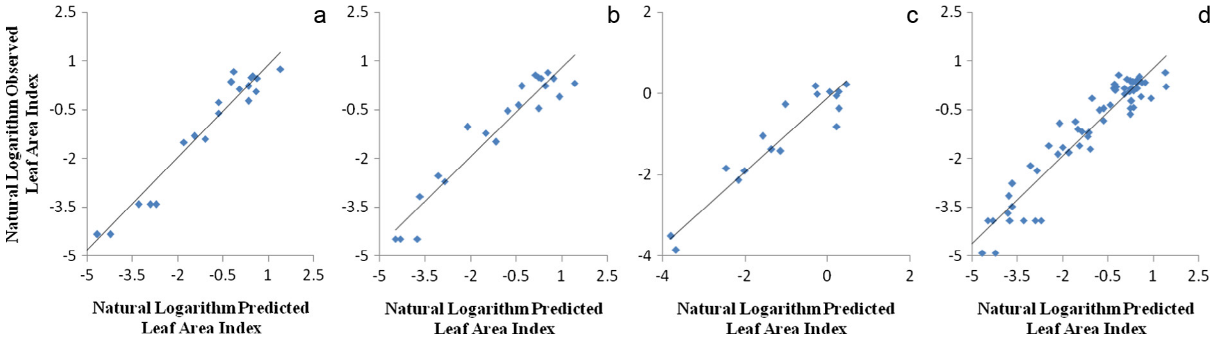

Figure 2 Relationship between observed and predicted Leaf Area Index and Number of Nodes of pumpkin at 20 April (a), 21 May (b), 21 June (c) and all planting dates (d).

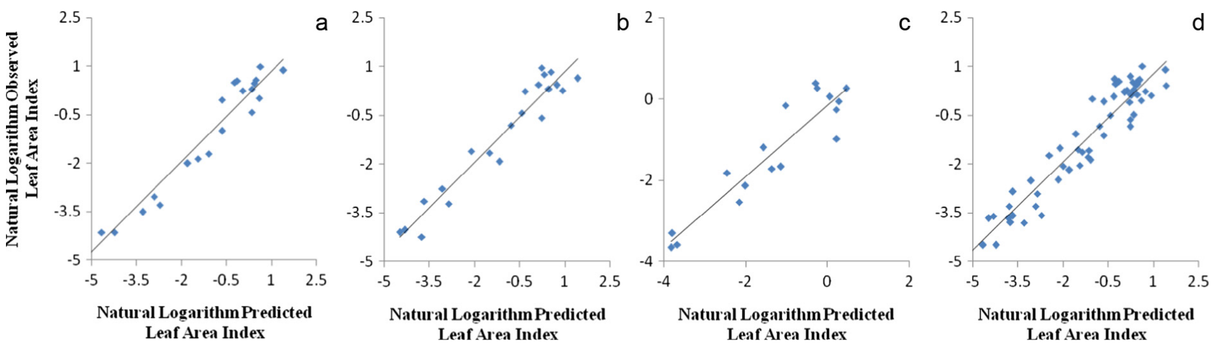

Figure 3 Relationship between observed and predicted Leaf Area Index and Plant Height of pumpkin at 20 April (a), 21 May (b), 21 June (c) and all planting dates (d).

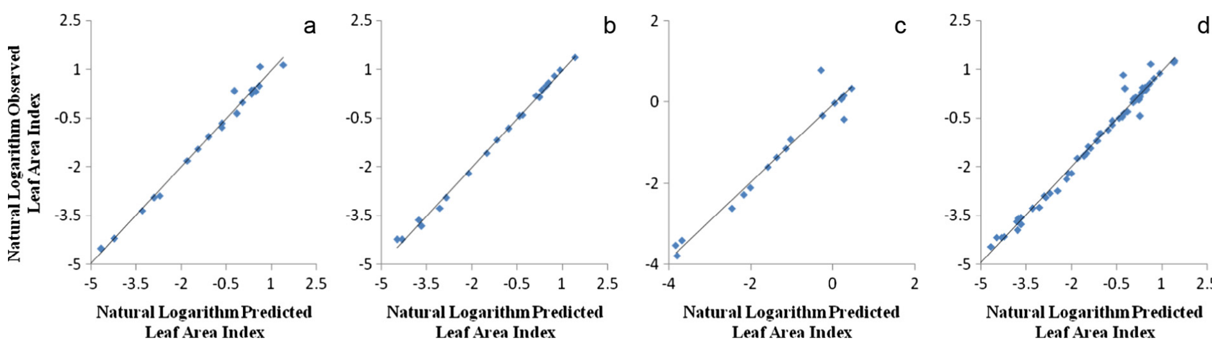

Figure 4 Relationship between observed and predicted Leaf Area Index and Leaf Fresh Weight of pumpkin at 20 April (a), 21 May (b), 21 June (c) and all planting dates (d).

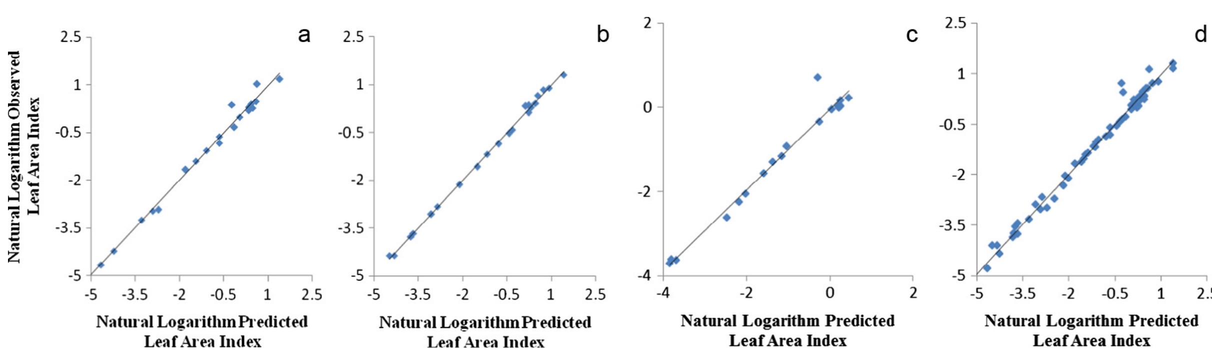

Figure 5 Relationship between observed and predicted Leaf Area Index and Leaf Dry Weight of pumpkin at 20 April (a), 21 May (b), 21 June (c) and all planting dates (d).

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dry weight to estimate LAI. Awal et al. (2004) on oil palm and Ma et al. (1992) on peanuts reported high correlation between leaf dry weight and leaf area using the linear and nonlinear regression models. Bakhshandeh et al. (2010) on soybeans, Tsialtas and Maslaris (2008) on sugar beets and Retta et al. (2000) on several grass species used nonlinear models to describe the relations of leaf dry weight and total dry weight of vegetative parts with the leaf area which among their results, can be referred to the results of Rahemi Karizaki et al. (2006) for peas, Akram-Ghaderi and Soltani (2012) for cotton, Payne et al. (1991) for millet, Sharratt and Baker (1986) for lucerne, Ramos et al. (1983) for barley, Zrust et al. (1974) for potato, Shih et al. (1981) for sweet sorghum, Lieth et al. (1986) for soybean and Aase (1978) for wheat. Since measuring the assessed traits is simpler and gets measured fast without the use of equipped instruments compared to measuring leaf area, therefore the traits can be used to estimate leaf area.

4. Conclusion

The results showed that there are high model relations between leaf area index and leaf no. per plant, node no. per main stem, plant height, leaf dry and fresh weight (with R^2 = 0.90, 0.90, 0.90, 0.98 and 0.98 respectively). The fresh weight and dry weight were better able to estimate leaf area and between them, wet leaf weight was selected as the best attribute due to the speed and ease of measurement and fewer required facilities (only needs scales, without the need for oven). These relationships can be used in pumpkin simulation models and a quick and easy estimation of the LAI when leaf area measurement instruments are not available.

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