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Leaf area index assessment for tomato and cucumber growing period under different water treatments

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ABSTRACT

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The aim of this study was to assess the leaf area index (LAI) of tomato and cucumber using an AccuPAR-LP-80-ceptometer to find the influence of irrigation. LAI was also determined by destructive sampling for comparison. The research was conducted at the Liaoning Water Conservancy Institute, North China in 2016. A randomized block design was used to test the influence of four treatments corresponding to field water capacity. Full irrigation ($W_{1.0}$), 15% ($W_{0.85}$), 25% ($W_{0.75}$) and 35% ($W_{0.65}$) water deficit were applied using the drip system. Regression model was developed to estimate LAI in response to irrigation. The results show that there is no difference between the two methods. The highest LAI obtained for tomato and cucumber was 5.21 and 3.21 m^2/m^2, respectively, with $W_{0.85}$ at 70-days after transplanting, which corresponds with destructive results. This result was found 11% higher and equal compared with $W_{1.0}$ for tomato (4.62) and cucumber (3.21), respectively. For both crops, LAI was found significantly influenced at 50-days after transplanting. It also indicated that LAI significantly influenced (by 15%) deficit irrigation for both crops and methods that achieved the highest yield. The predicted LAI was obtained best-fitting with the observed values, which indicated that the AccuPAR-ceptometer is suitable to be used.

Keywords: drip irrigation; *Solanum lycopersicum*; *Cucumis sativus*; microclimate; water consumption; non-destructive

Leaves are an active border of exchanging energy, carbon and water in between plants, canopies and atmosphere. These verdurous organs help to feed plants in relation with photosynthesis and evapotranspiration. Leaf area index (LAI) is a dimensionless variable, represents the structural attribute of leaf components, estimated by area of leaf per unit area of soil surface (Cutini et al. 1998). It also represents plants leaf photon interception, which highly influences biomass as well as yield production that is directly related with water consumption (Firouzabadi et al. 2015). It stimulates how much light moves through a canopy and influences the microclimate; thus, it can be used as an indicator of canopy health or development. Thus, the assessment of LAI is essential and very significant in most of the physiological, horticultural and agronomic studies that involve crop growth corresponding to yield (Guo and Sun 2001).

Many studies have been undertaken focused on the assessment of LAI with direct and indirect techniques. Although direct methods of LAI measurement are accurate, they are sample-destructive, labour-intensive and their execution is difficult due to timely monitoring of leaf area variation in large-scale experimentation. Thus, researchers have shifted their attention to the use of digital technologies (indirect) avoiding destructive sampling. Firouzabadi et al. (2015) measured dimension of

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field leaves (non-destructive), sketched on paper, scanned and calculated using AutoCAD, which is, however, time-consuming. Also other studies were undertaken for the assessment of LAI for different crops using different digital technologies, such as: Licor LAI-2000 Plant Canopy Analyzer (Cutini et al. 1998), digital images (Campillo et al. 2010), WinSCANOPY analysis system (Du et al. 2017), PAR (photosynthetically active radiation) interception mapping method (Zhang et al. 2015), PAR quantum sensor, GaAsP photosensor (Rosati et al. 2001) and so forth. They also have some perplex issues. For example, Licor LAI-2000 provides B (bad) reading for sky condition, measurement variation and operator error. So far, the assessment of LAI based on the AccuPAR-LP-80-ceptometer instrument on the standing vegetables leaves has been rarely used, especially for tomato and cucumber. Using ceptometer, measurement of LAI is an easy, quick and non-destructive method which has been used to observe various agronomic (switch grass, sagebrush-steppe, rangelands, maize, giant reed etc.) physiology and vegetative growth (Finzel et al. 2012, Francone et al. 2014). Nevertheless, this instrument has not been used in horticultural crops such as tomato and cucumber. Thus, using a ceptometer for LAI assessment in horticultural crops remained unnoticed. Therefore, this study reported the LAI of tomato and cucumber growing periods that were influenced by water consumption.

MATERIAL AND METHODS

Experimental outline. The research was conducted in an 855 m^2 (86 m × 9.94 m) greenhouse area situated at 123°31'E and 42°09'N. The greenhouse was not equipped with the heating and ventilation system and the average temperature and humidity during the cropping period were maintained at 21.22°C and 69.96%, respectively. The soil type in the greenhouse was mainly clay-loamy with 24% field capacity and 1.65 g/cm^3 bulk density. A randomized block design was used to test the influence of four water treatments, such as: full irrigation ($W_{1.0}$), 15% ($W_{0.85}$), 25% ($W_{0.75}$) and 35% ($W_{0.65}$) deficit irrigation. It means that irrigation was scheduled when available soil water holding capacity was ≤ 100%, ≤ 85%, ≤ 75% and ≤ 65%. The tomato (local cv. Ao Te You) and cucumber (cv. Maria) were planted on 26 February, 2016 using a row system. Total planted area of individual crop was 184.4 m^2 in which each treatment plot was 7.0 m long and 6.6 m wide. The row spacing of both plantations was kept 0.6 m and plant-to-plant distance was maintained at 0.4 m. The plants were irrigated using 0.2 mm thick polyethylene-type drip tube (16 mm outer diameter) at 0.3 m water dripping space, which was kept at the centre of two adjacent rows with 1.38 L/h discharge. Two types of fertilizer were applied equally in all treatments during land preparation: compound fertilizer (NPK) – 375 kg/ha and organic potash – 300 kg/ha. The plants were trained for vertical growth using rope.

The amount of water was estimated using equation (1) for a schedule of irrigation as follows (Nong et al. 2009):

$$m = 0.1(\beta_f - \beta_0)H\rho\gamma \qquad (1)$$

Where: m – irrigation depth (mm); β_f – moisture content at field capacity (%); β_0 – moisture content before irrigation (%); H – soil depth (m); ρ – soil bulk density (t/m^3); γ – wetting parameter (%).

The amount of irrigation was calculated into m^3 to be easily read in water-meter. Soil moisture content was determined using the gravimetric method at 20 cm soil depth. The cumulative water application depth (mm) in each treatment at different days after transplanting for both crops is illustrated in Figure 1.

Measurement of LAI. The LAI values were measured throughout the growing period starting at 40 days after transplanting in 3 replications in each treatment at 10-day intervals and lasted until 4 times using the AccuPAR ceptometer LP-80, Decagon Devices Germany. The ceptometer is a battery-operated menu driven device, which is used to measure light interception in plant canopies to calculate LAI. Its main components are an integrated microprocessor-driven data logger and a probe with 80 sensors. Data were collected from menu screen by inserting the probe into canopy.

For determining LAI in a destructive way, all leaves were removed separately from randomly selected 3 plants from each treatment at the last sampling date. The collected leaves (tomato, 10–12 per plant) and (cucumber, 15–17 per plant) were placed into a rectangular sketch of a white paper. Top view photograph was taken using a digital camera as presented in Figure 2. Leaf area (LA) was determined by scanning of images through leaf area

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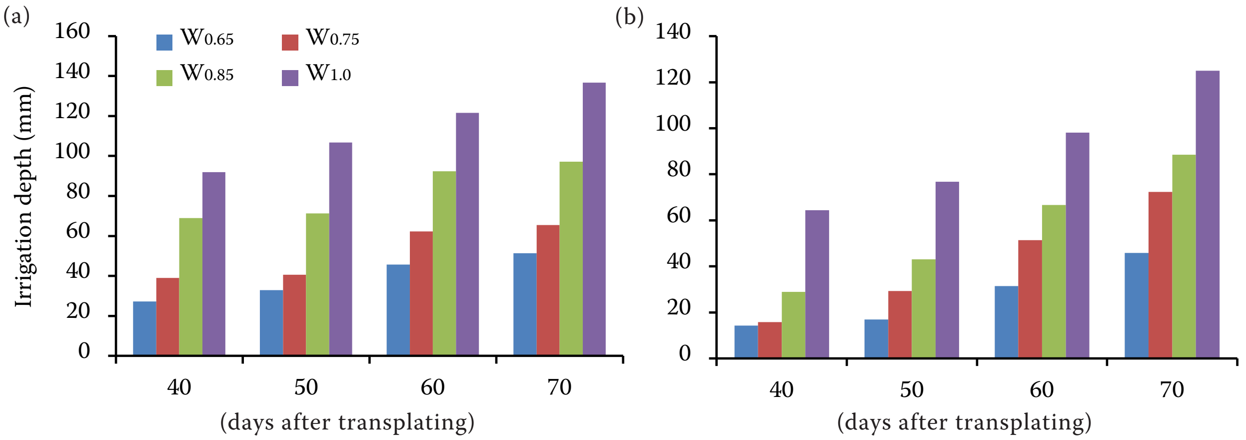

Figure 1. Cumulative water application depth for different treatments illustrated at specific days after transplanting (a) tomato and (b) cucumber. $W_{1.0}$ – full irrigation; $W_{0.85}$ – 15%, $W_{0.75}$ – 25%, $W_{0.65}$ – 35% deficit irrigation

software (Chen et al. 2012), in which the model equation (2) was used as follows:

$$LA_i = \frac{A_r}{N_r} \times N_i \qquad (2)$$

Where: LA_i – area of i^{th} leaf (mm^2); A_r – actual rectangular area on white paper (mm^2); N_r – total number of pixel into the rectangle; N_i – i^{th} number of the leaf element. Total LA per plant was calculated by adding of all LAs. The LAI was calculated as total LA of a plant divided by the ground surface (row-row × plant-plant distance) occupied by the plant.

Data analysis. Data were statistically analysed by one-way ANOVA. Mean differences were calculated for significance by the Tukey's-b test at $P < 0.05$ significant level. IBM-SPSS statistics 19.0 version (New York, USA) was used to analyse the data. Regression analysis was also carried out for developing the model for LAI with water consumption. The objective of this model ($Y = A + BX$) was to estimate the predicting LAI in relation with water application. Where: Y, A, B and X stand for observed LAI, constant value, coefficient of variance and irrigation for the respective treatment. Coefficient of determination (R^2) and root mean square error (RMSE) were used to test the models for validity.

RESULTS AND DISCUSSION

Effect of treatments on LAI. The effect of water on LAI progression and one-way ANOVA results under ceptometer and destructive method at different days after transplanting for tomato and cucumber are given in Table 1. The highest LAI values for tomato and cucumber were obtained under cep-

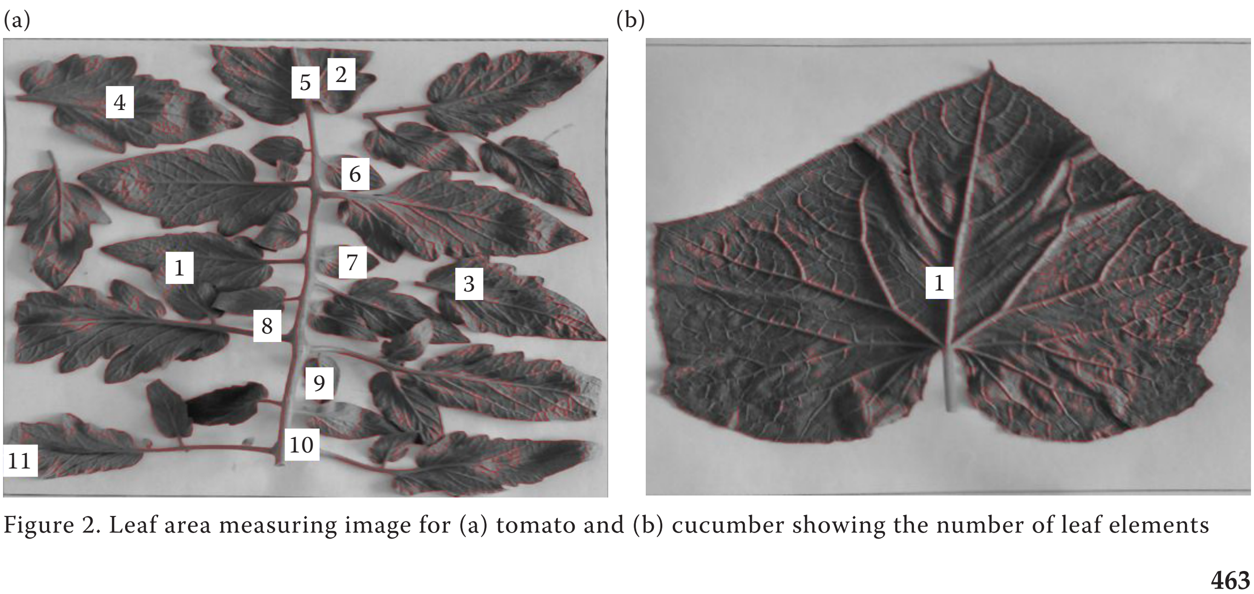

Figure 2. Leaf area measuring image for (a) tomato and (b) cucumber showing the number of leaf elements

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Table 1. Effect of treatments on leaf area index (LAI)[1] of tomato and cucumber

Treatment	Ceptometer (non-destructive) method				Destructive method (70 D)	Yield (kg/m^2) seasonal
	40 D	50 D	60 D	70 D		
Tomato						
$W_{0.65}$	1.97 ± 0.38^a	2.18 ± 0.18^a	3.14 ± 0.08^a	4.98 ± 0.17^a	2.96 ± 0.37^a	7.89^a
$W_{0.75}$	1.88 ± 0.27^a	2.25 ± 0.18^a	3.13 ± 0.56^a	4.78 ± 0.05^a	3.81 ± 0.34^b	9.07^{ab}
$W_{0.85}$	2.31 ± 0.67^a	2.77 ± 0.37^b	3.51 ± 0.47^a	5.21 ± 0.51^a	4.22 ± 0.13^b	10.34^b
$W_{1.0}$	2.10 ± 0.13^a	2.39 ± 0.27^a	3.14 ± 0.33^a	4.62 ± 0.33^a	4.09 ± 0.24^b	9.86^{ab}
ANOVA						
Sum of squares	1.377	0.554	1.279	0.803	0.666	6.451
Mean square	0.172	0.069	0.160	0.100	0.083	0.806
F-value	0.600	3.073	0.643	1.983	11.535	4.274
Significance	ns	*	ns	ns	**	*
Cucumber						
$W_{0.65}$	1.53 ± 0.61^a	2.14 ± 0.49^b	2.91 ± 0.05^b	3.10 ± 0.14^a	2.64 ± 0.07^a	8.35^a
$W_{0.75}$	1.80 ± 0.50^a	2.19 ± 0.35^b	2.52 ± 0.43^{ab}	3.17 ± 0.18^a	3.05 ± 0.07^a	10.07^{ab}
$W_{0.85}$	1.49 ± 0.52^a	2.07 ± 0.12^b	2.69 ± 0.30^b	3.21 ± 0.23^a	3.09 ± 0.48^a	11.16^b
$W_{1.0}$	0.64 ± 0.08^a	1.25 ± 0.24^a	1.77 ± 0.41^a	3.21 ± 1.10^a	3.01 ± 0.32^a	10.65^{ab}
ANOVA						
Sum of squares	1.807	0.877	0.885	2.611	0.678	7.171
Mean square	0.226	0.110	0.111	0.326	0.085	0.896
F-value	3.359	5.429	6.606	0.026	1.496	4.996
Significance	*	*	**	ns	ns	*

[1]Mean value (m^2/m^2) ± standard deviation; D – days after transplanting; letters within column indicate that mean values are significantly different by the Tukey's-b test; $^{**}P < 0.01$; $^{*}P < 0.05$; ns – not significant at $P > 0.05$. $W_{1.0}$ – full irrigation; $W_{0.85}$ – 15%, $W_{0.75}$ – 25%, $W_{0.65}$ – 35% deficit irrigation

tometer method 5.21 and 3.21 with $W_{0.85}$ at 70 days after transplanting, respectively. In tomato, the highest LAI with $W_{0.85}$ was found 11% higher than with full irrigation ($W_{1.0}$, 4.62). Similar result was reported by Harmanto et al. (2005) stating that the maximum LAI was 4.8 with 75% of ET_c (actual evapotranspiration) for greenhouse tomato. Campillo et al. (2010) and Pires et al. (2011) also reported that the highest obtained LAI for greenhouse tomato and cucumber was 3.7 and 3.66, respectively, which is consistent with the present study. However, in cucumber, LAI values for all deficit water applications ($W_{0.65}$, $W_{0.75}$, $W_{0.85}$) were found higher than with full irrigation ($W_{1.0}$) except 70 days after transplanting. Xiaolei and Zhifeng (2004) and Kläring et al. (2012) reported that the highest recorded cucumber LAI was 3.5 and 3.3, respectively. This was also found the most analogous with present study. Using ceptometer, the highest LAI for buffelgrass species was reported 3.46, 4.58 and 5.03 for Nueces, *Miscanthus* and Alamo, respectively (Johnson et al. 2010). It was for different vegetation, and thus it is also consistent with the present result. However, the ceptometer gave reliable readings for tomato and cucumber. It was also indicated that LAI values were obtained higher from the latest date of measurement (70 D (days) > 60 D > 50 D > 40 D) and from 15% deficit water application (Table 1). Moisture status with gas exchange are favourable for development of leaves' stomatal density, which functions in response to leaf water status and has correlation with specific leaf area corresponding to LAI. Moreover, soil nutrients, climate and other factors like location and management practices influenced LAI. In destructive method, $W_{0.85}$ treatment also gave the highest LAI for tomato (4.22) and cucumber (3.09). In that case, LAI values obtained were a little bit lower than at ceptometer method for both crops. The

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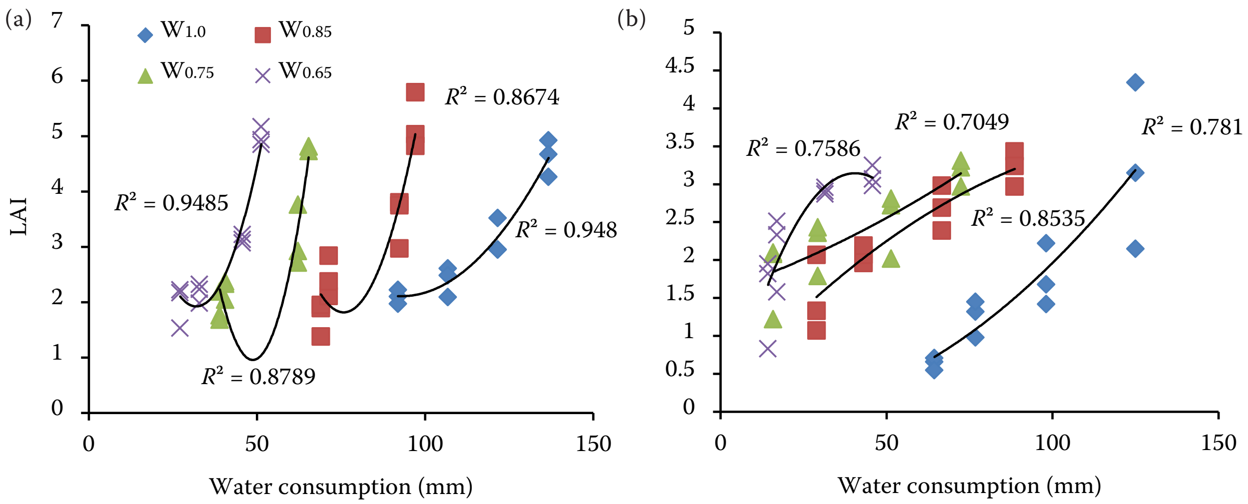

Figure 3. Response of leaf area index (LAI) under different water consumption at (a) tomato and (b) cucumber. $W_{1.0}$ – full irrigation; $W_{0.85}$ – 15%, $W_{0.75}$ – 25%, $W_{0.65}$ – 35% deficit irrigation

reason is that in this method, leaves were separated from plants and the LAI was calculated. Hence, compared to the use of ceptometer, there was no external influence from surrounding leaves and radiation.

The evolution of LAI values measured by ceptometer for tomato and cucumber are depicted in Figure 3. The LAI for tomato in different deficit applications displayed a steep asymptotic growth with increasing water dose, while in full irrigation it displayed a mild asymptotic development (Figure 3a). However, in cucumber all water applications had a similar influence, as shown by the mild asymptotic upright curve on LAI development except 35% deficit ($W_{0.65}$) application (Figure 3b). The R^2 values were found greater for tomato (0.86 to 0.95) than cucumber (0.70 to 0.85) which indicates that tomato crop is less drought-sensitive than cucumber. In destructive method, the LAI values for both crops showed an increasing relation with the measured leaf area as depicted in Figure 4. The power relations for tomato (R^2 = 0.95) and cucumber (R^2 = 0.97) indicated that the evolution of LAI has a highly significant correlation with the progression of LA. It also indicated that the highest LAI influenced the increased yield. It could be due to drip irrigation that was more beneficial to the plant-root system. Therefore, in the controlled environmental conditions, tomato and cucumber can grow vigorously up to certain water application deficit. It was also recognized that the AccuPAR LP-80 ceptometer could be effectively used to assess LAI for both crops.

The statistical analysis shows that the LAI values for tomato under the ceptometer method were significantly (P < 0.05) influenced by irrigation only at 50 days after transplanting. More specifically, $W_{0.85}$ shows a significant difference with all treatments. In the destructive method, $W_{0.65}$ was found significantly (P < 0.01) different than the other levels. In case of cucumber, all treatments significantly (P < 0.05) influenced LAI values except 70 days after transplanting. At 50 days after transplanting $W_{1.0}$ was found significantly different compared to the other treatments; at 60 days, it also showed significant differences. However, in the destructive method it was revealed as a non-significant influence.

The results clearly show that LAI indices are influenced differently by the two methods. In

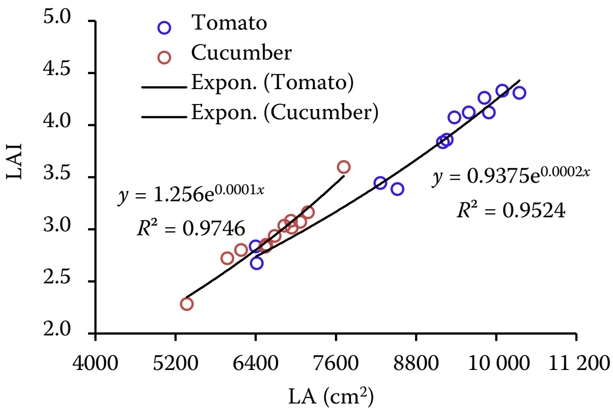

Figure 4. Power relation of leaf area index (LAI) vs measured leaf area (LA) in destructive method

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Table 2. Regression models for leaf area index (LAI) of tomato and cucumber

Crop	Treatment	Regression model	R^2	RMSE	Equa.
Tomato	$W_{0.65}$	$LAI = 0.11391 \times W_{0.65} - 1.402633^{***}$	0.83	0.541	(3)
	$W_{0.75}$	$LAI = 0.082944 \times W_{0.75} - 1.28526^{**}$	0.76	0.620	(4)
	$W_{0.85}$	$LAI = 0.098186 \times W_{0.85} - 4.870437^{***}$	0.81	0.644	(5)
	$W_{1.0}$	$LAI = 0.0557815 \times W_{1.0} - 3.311784^{***}$	0.86	0.405	(6)
	all	$LAI = 0.0004175 \times LA - 0.0457042^{***}$	0.96	0.1175	(7)
Cucumber	$W_{0.65}$	$LAI = 0.0456848 \times W_{0.65} + 1.183037^{**}$	0.67	0.447	(8)
	$W_{0.75}$	$LAI = 0.0229892 \times W_{0.75} + 1.448277^{**}$	0.70	0.354	(9)
	$W_{0.85}$	$LAI = 0.0282201 \times W_{0.85} + 0.763213^{***}$	0.84	0.302	(10)
	$W_{1.0}$	$LAI = 0.409193 \times W_{1.0} - 2.006429^{***}$	0.77	0.557	(11)
	all	$LAI = 0.0004929 \times LA - 0.3370021^{***}$	0.95	0.0754	(12)

$^{**}P < 0.01$; $^{***}P < 0.001$; R^2 – coefficient of determination; RMSE – root mean square error. $W_{1.0}$ – full irrigation; $W_{0.85}$ – 15%, $W_{0.75}$ – 25%, $W_{0.65}$ – 35% deficit irrigation

destructive sampling, as it is time- and labour-expensive, all leaves are needed to be harvested, which affects the total yield. In contrast, ceptometer can be used carefully avoiding the clumping error using the finite length (80 cm) of probe, which has five groups of sensors. The displayed LAI was a programme-averaged reading from five groups of sensors, which can be used to calculate the zenith angle automatically by optimizing the gap fraction (Peper and McPherson 1998). Therefore, the ceptometer method for assessment of LAI is less biased and more valid.

Model validation performance. The model equations to estimate LAI in response to water consumption under ceptometer method for tomato (equations 3–6) and cucumber (equations 8–11) and under destructive method for tomato (equation 7) and cucumber (equation 12) are listed in Table 2. These models for calculating LAI were analysed as statistically significant ($P < 0.01$). In the ceptometer method, the R^2 and RMSE were obtained in an appropriate range for tomato (0.76 to 0.86 and 0.405 to 0.644) and cucumber (0.67 to 0.84 and 0.302 to 0.557), respectively, which represents the better performance. To compare, in the destructive method for tomato with all treatments, R^2 and RMSE of 0.96 and 0.118 were obtained, respectively, which also displayed the best fitting of the collected data. The polynomial relation for both methods for all treatments showed a similar curvature trend following a decline after full ground cover. The R^2 values for ceptometer (0.86) and destructive (0.97) methods were found highly significant in between the observed and predicted LAI values, as depicted in Figure 5, which indicates the best relation of the two methods.

On the other hand, for cucumber, R^2 (0.95) and RMSE (0.754) indicated more accurate results collectively for all treatments. The polynomial relation for all treatments for both methods also displayed a curve-linear pattern which strung with an initial linear stage followed by maximum asymptotic trend at full vegetation stage, in which high R^2 for ceptometer (0.80) and destructive (0.97) method indicated the best relation, which speci-

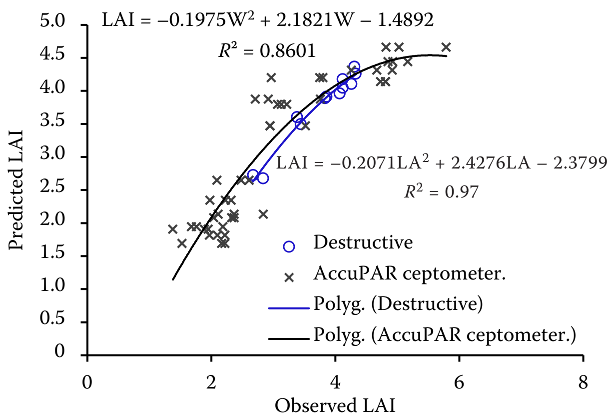

Figure 5. Relationship between the observed and predicted leaf area index (LAI) of tomato for ceptometer and destructive method of all treatments. W – water consumption; LA – leaf area

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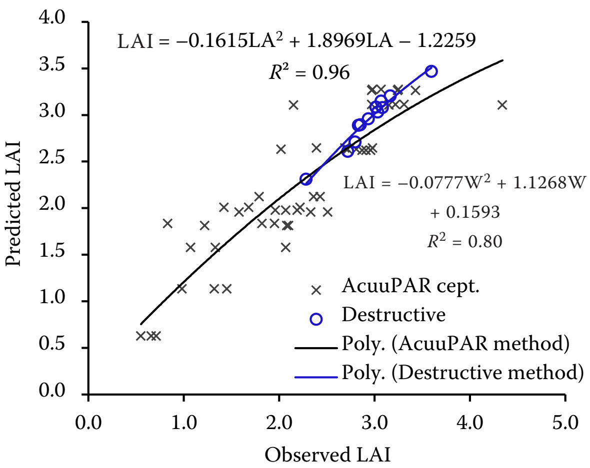

Figure 6. Relationship between the observed and predicted leaf area index (LAI) of cucumber for ceptometer and destructive method of all treatments. LA – leaf area; W – water consumption

fied the methods accuracy as depicted in Figure 6. Likewise, Francone et al. (2014) reported that the LAI measurements with ceptometer for maize, giant reed and natural grassland exposed good performance (R^2 = 0.86, 0.92 and 0.88) and (RMSE = 0.41, 0.49 and 0.96); it endorsed the reliability of the ceptometer used. This good correlation coefficient also indicated that using a ceptometer for LAI determination in vegetable crops is appropriate. Therefore, it may be concluded that this non-destructive, indirect measurement of LAI using the AccuPAR ceptometer is appropriate for its rapid, automatic and reliable reading, and it could be used precisely in large-scale events.

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