Canopy Cover and Leaf Area Index Relationships for Wheat, Triticale, and Corn

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ABSTRACT

Previously collected data sets that would be useful for calibrating and validating AquaCrop contain only leaf area index (LAI) data but could be used if relationships were available relating LAI to canopy cover (CC). The objective of this experiment was to determine relationships between LAI and CC for corn (*Zea mays* L.), winter wheat (*Triticum aestivum* L.), and spring triticale (× *Triticosecale* spp.) grown under dryland or very limited irrigation conditions. The LAI and CC data were collected during 2010 and 2011 at Akron, CO, and Sidney, NE, using a plant canopy analyzer and point analysis of above-canopy digital photographs. Strong relationships were found between LAI and CC that followed the exponential rise to a maximum form. The relationship for corn was similar to a previously published relationship for LAI <2 m^2 m^{-2} but predicted lower CC for greater LAI. Relationships for wheat and triticale were similar to each other.

In semiarid regions where environmental conditions (particularly highly variable precipitation) make production decisions uncertain about which crops to plant, how often to fallow, and which crop sequence should be used, cropping systems simulation models have been successfully used to analyze the effects on productivity of varying cropping intensity, crop sequence, N management, and plant population (Lyon et al., 2003; Saseendran et al., 2004, 2010), as well as effects due to varying location, weather, and soils (Saseendran et al., 2009). There are often difficulties in extending field research results from a specific season and site to other situations. The use of models may assist in this process if they are validated and if specific growth parameters are adequately predicted. Lyon et al. (2003) noted that field research results can sometimes be limited to the period of time in which they were conducted, potentially leading to some inaccurate conclusions. Crop modeling with long-term climate data provides the opportunity to reduce the occurrence of these inaccurate conclusions that may result from short-term field studies conducted during a period that does not adequately represent the true climate variability (Lyon et al., 2003; Staggenborg and Vanderlip, 2005). Models have been used to extend field research results to make management decisions in the central Great Plains (Saseendran et al., 2010), including optimal planting date, crop rotation sequencing, crop–fallow decisions, evaluating profitability of alternative crops, and limited irrigation management. Additionally, modeling is a tool that can be used by producers to avoid the risks encountered in the adoption of new crops (e.g., canola [*Brassica napus* L. ssp. *napus*]) and new crop rotation sequences (Nielsen et al., 2012; Staggenborg and Vanderlip, 2005).

AquaCrop (FAO, 2012) is a computer model developed by the Land and Water Division of the FAO with the goal of increasing water use efficiency in food production (Araya et al., 2010). AquaCrop was designed to simulate biomass and seed yield responses of crops to water, especially under conditions where water is the liming factor (Steduto et al., 2009). It has been used to simulate production for barley (*Hordeum vulgare* L.; Araya et al., 2010), corn (Hsiao et al., 2009), cotton (*Gossypium hirsutum* L.; Farahani et al., 2009), onion (*Allium cepa* L.) and potato (*Solanum tuberosum* L.) (Domínguez et al., 2011), quinoa (*Chenopodium quinoa* Willd.; Geerts et al., 2009), and wheat (Andarzian et al., 2011; Salemi et al., 2011).

AquaCrop uses a relatively small number of parameters that can be separated into four categories: climate, crop, management, and soil (Raes et al., 2009). In the crop category, AquaCrop simulates green-crop CC as opposed to LAI to describe growth and canopy development. There are only a few previously reported relationships between LAI and CC for crop species. Hsiao et al. (2009) reported the following relationship for corn:

$$CC = 100.5\left[1-\exp\left(-0.60\ \mathrm{LAI}\right)\right]^{1.2} \qquad [1]$$

No details were given regarding how LAI and CC were measured.

Farahani et al. (2009) reported the following relationship for cotton:

$$CC = 100\left[1-\exp\left(-0.77\ \mathrm{LAI}\right)\right] \qquad [2]$$

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Abbreviations: CC, canopy cover; LAI, leaf area index.

Table 2. Growing-season precipitation and supplemental irrigation amounts for corn, winter wheat, and spring triticale at Akron, CO, and Sidney, NE, in 2010 and 2011.

Location	Year	Crop	Growing-season precipitation	Supplemental irrigation
			mm	
Akron, CO	2010	corn	163	108
		wheat	263	51
		triticale	na†	na
	2011	corn	273	89
		wheat	371	25
		triticale	222	25
Sidney, NE	2010	corn	252	166
		wheat	461	48
		triticale	225	10
	2011	corn	na	na
		wheat	484	83
		triticale	270	66

† na, not available. Triticale unavailable at Akron, CO, in 2010 due to planting error. Corn not planted at Sidney, NE, in 2011.

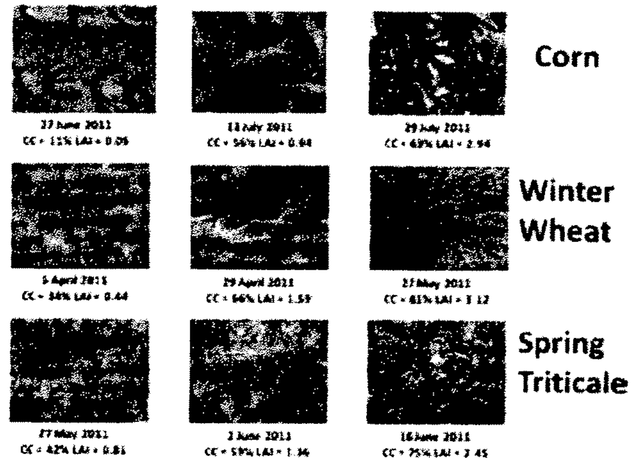

Fig. 1. Representative photographs of corn, winter wheat, and spring triticale at Akron, CO, and the associated measured canopy cover (CC) and leaf area index (LAI).

the horizon and at arm's length to the south of the photographer at midday to minimize shadows. Photographs were taken above the canopy at four locations per plot. For photographs of corn taken after 12 July, the photographer climbed a stepladder to get above the canopy. Each digital image was subsequently analyzed using SamplePoint measurement software version 1.53 (Booth et al., 2006; http://www.samplepoint.org/). The SamplePoint software was set to select 64 randomly located points in each image. The software operator classified each of the 64 points as either leaf or soil. The CC percentage was calculated as the fraction of sampled points that contacted the crop canopy. The results from the four areas photographed in each plot were averaged to give the average CC per plot at each sampling time.

Both LAI and CC values were averaged across the four replicate plots for each combination of the two crop rotations and two irrigation levels. Relationships between CC and LAI were created with SigmaPlot for Windows version 11.0 graphing and analysis software (Systat Software) using the nonlinear regression wizard to fit a curve to the data. The regression wizard used the Marquardt–Levenberg algorithm in an iterative process to find the regression coefficients (parameters) that gave the best fit between the equation and the data (SigmaPlot, 2008, p. 667–670; Marquardt, 1963). Several equation forms were evaluated (two-, three-, and four-parameter versions of exponential rise to a maximum, logarithmic, and power forms), with the R^2 value used to determine goodness-of-fit. There was no functional difference between the forms, but the R^2 value was maximized with the exponential rise to a maximum form. There was no difference in the R^2 value among the two-, three-, and four-parameter versions of this equation form. We therefore decided to use the three-parameter version so that the fitted parameters could be directly compared with the parameters given by Hsiao et al. (2009) for corn as shown in Eq. [1] above.

RESULTS AND DISCUSSION

Representative photographs of corn, wheat, and triticale canopies on three dates for each crop are shown in Fig. 1, with the measured CC and LAI noted. The SamplePoint software

Table 3. Dates of leaf area index measurements and canopy cover photographs and associated crop growth stage for corn, winter wheat, and spring triticale at Akron, CO, and Sidney, NE, in 2010 and 2011. Triticale data are unavailable for Akron, CO, in 2010 due to a planting error, while corn was not planted at Sidney, NE, in 2011.

Location	Year	Crop	Sampling date (growth stage†)							
Akron, CO	2010	corn	11 June (V5)	18 June (V6)	24 June (V8)	1 July (V9)	29 July (R1)			
		wheat	14 April (pseudostem)	27 April (jointing)	13 May	25 May (boot)	3 June (anthesis)	11 June (milk)		
	2011	corn	21 June (V5)	28 June (V6)	5 July (V8)	12 July (V10)	20 July (V13)	29 July (V19)		
		wheat	5 April (pseudostem)	29 April (jointing)	5 May	13 May	20 May (boot)	27 May	6 June (anthesis)	10 June (watery ripe)
		triticale	9 May	20 May	27 May	2 June (jointing)	10 June (boot)	16 June (heading)		
Sidney, NE	2010	corn	30 June (V8)	27 July (anthesis)						
		wheat	28 April (jointing)	18 May	4 June (anthesis)					
		triticale	1 June (jointing)	22 June (heading)						
	2011	wheat	3 May (jointing)	9 June (anthesis)						
		triticale	1 June (jointing)	22 June (heading)						

† Corn growth stages as defined by Ritchie and Hanway (1986). Wheat and triticale growth stages as defined by Nelson et al. (1988).

predicted by Eq. [5] for triticale were about 93% of the CC values predicted by Eq. [4] for wheat. Data were only available for LAI values up to 2.25 $m^2 m^{-2}$, so we are somewhat unsure about what the maximum CC value for triticale would be at higher LAI values. It is probable that the data at higher LAI values would show a relationship very similar to what was found for winter wheat because the structure of these two grasses is similar and the row spacing was the same. The relationship for triticale should be further investigated, however, and confirmed with data for situations with LAI > 2.5 $m^2 m^{-2}$.

Prediction of CC from LAI using Eq. [3], [4], and [5] can enable data from completed experiments to be used to calibrate and validate AquaCrop or other models that rely on values of CC to quantify plant development. Additionally, the relationships given in Eq. [3], [4], and [5] can be rewritten solving for LAI so that researchers who only have a relatively inexpensive digital camera available to them can quantify treatment effects on LAI development for these three crops without having to invest in more expensive equipment or time-consuming destructive sampling. For example, Eq. [3] would become:

$$\mathrm{LAI} = \frac{\ln\left(1 - \sqrt[0.9567]{CC/76.78}\right)}{-0.8105} \quad [6]$$

CONCLUSIONS

Data collected on corn, winter wheat, and spring triticale during 2 yr at two locations from two cropping systems and two water treatments were analyzed to determine predictive relationships between LAI and CC. The relationship for corn was found to be similar in form (exponential rise to a maximum) to one previously given in the literature and predicted similar values of CC when LAI was <2 $m^2 m^{-2}$. At greater LAI values, however, the new relationship predicted lower CC values than the relationship from the literature. The difference may have to do with stand density differences. The relationships found for winter wheat and spring triticale were similar to each other and predicted greater canopy cover values at LAI <2 $m^2 m^{-2}$ than the relationship found for corn. The relationships will be valuable to individuals that wish to use AquaCrop to model data sets that had only LAI recorded. Additionally, the relationships can be rewritten such that LAI is a function of CC so that LAI can be quickly and inexpensively estimated from digital photographs of CC made with a low-cost digital camera.

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