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IRRIGATION AND TILLAGE MANAGEMENT EFFECTS ON CANOPY FORMATION IN CORN

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ABSTRACT

Effects of canopy formation and function are frequently represented in irrigation management models by crop coefficients, which can be used to calculate expected crop water requirements. Soil tillage alters the micro-environment of a developing corn canopy. The objective of this study was to evaluate irrigation capacity and tillage effects on seasonal changes in maize canopy and above-ground biomass productivity. Leaf area index (LAI) and above-ground biomass (AGB) were quantified by non-destructive methods during four growing seasons for corn under two irrigation capacities (1”/4 days or 1”/8 days) and three tillage regimes (no till (NT), strip till (ST), or conventional till (CT)). Irrigation capacity and tillage effects were evaluated for each sampling period; seasonal trends were evaluated for year and treatment effects. CT management resulted in earlier canopy formation and greater AGB accumulation during early vegetative growth in three of four years. NT management resulted in extended canopy duration and greater AGB at tassel stage in two of four years; ST management resulted in greatest canopy duration in one year. Evaluated over the four years, seasonal trends in LAI indicated earliest development under CT and delayed canopy development under NT management. The intermediate rate of canopy development of corn under ST management, and favorable yield and water productivity, indicates utility of ST management for irrigated corn production.

INTRODUCTION

The canopy of maize crops generates the structural biomass and carbohydrates which support grain yield formation. Stomata embedded in leaves mediate the atmospheric demand which results in the transpiration component of evapotranspiration (ET). Effects of canopy formation are frequently represented in irrigation management models by crop coefficients, which can be combined with reference or potential ET to calculate expected crop water requirements (Allen et al., 1998). The relationship of crop canopy formation and function to crop water requirements suggest the question: *Can crop management alter canopy formation and subsequent productivity?*

Soil tillage alters the micro-environment of a developing corn canopy, affecting crop residue distribution and soil physical properties in the tillage zone. Full surface coverage by residue was required to reduce energy-limited evaporation by 50% or more, relative to bare soil with no shading by crop canopy; partial residue coverage (25% to 75%) resulted in limited evaporation suppression relative to that of bare soil with no shading (Klocke et al., 2009). Corn grown under NT management required five to seven days longer to reach V6 development stage than corn under CT management in Ontario (Fortin, 1993). Corn yields were numerically greater under strip tillage (ST) and no tillage management, relative to conventional tillage management (Lamm et al., 2009). The objective of this study was to evaluate irrigation capacity and tillage effects on seasonal changes in maize canopy and above-ground biomass productivity.

PROCEDURES

A corn hybrid of approximately 110-day relative maturity (Dekalb DCK60-19 in 2004 and DCK60-18 in 2005 through 2007) was planted in 30” spaced circular rows on 8 May 2004, 27 April 2005, 20 April 2006, and 8 May 2007, respectively. The two hybrids differ only slightly, with the latter hybrid having an additional genetic modification of corn rootworm control. Three target seeding rates (27,000; 30,000; and 33,000 seeds/a) were superimposed onto each tillage treatment in a complete randomized block design. Irrigation was scheduled with a weather-based water budget but was limited to the three treatment capacities of 1 in. every 4, 6, or 8 days (IC-4, IC-6, and IC-8, respectively). This results in typical seasonal irrigation amounts of 12-20, 11-15, and 8-12 in., respectively. The weather-based water budget was constructed using data collected from a NOAA weather station located approximately 600 yd. northeast of the study site. The reference evapotranspiration (ETr) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ETr calculations used in this study are fully described by Lamm et al. (1987). The basal crop coefficients were calculated for the area by assuming 70 days from emergence to full canopy for corn with physiological maturity at 130 days.

Leaf area index (LAI) was quantified, approximately bi-weekly, by a non-destructive light transmission technique (Welles and Norman, 1991; LAI-2000 Plant Canopy Analyzer[i]). Three sets of four below-canopy measurements were each referenced to an above-canopy measurement, minimizing sensor exposure to direct (beam) irradiance. Readings were screened against apparent transmittance ratios exceeding 1 using the manufacturer’s software, FV2000. An inverse solution to a model of light transmission through a vegetative canopy, provided by the manufacturer, was used to quantify apparent LAI.

Above-ground biomass (AGB) was quantified by non-destructive allometric measurements from V6 through early grain fill stages. Three representative plants in each experimental unit were identified for repeated measure, commencing from V6 stage. Stem measurements included diameter of the second internode and at the upper sheath of the youngest fully expanded leaf, distance from the ground to the base of the youngest fully expanded leaf, and number of fully expanded leaves. For each sampling period, identical measurements were made for similar plants, outside the plot area but receiving similar management. These plants were cut at ground level and dried, to determine above-ground biomass. An allometric model was developed by regressing AGB against stem volume (calculated using cylindrical geometry) and cumulative growing degree days (cGDD). Coefficients of this model were then applied to in-plot measurements to calculate apparent above-ground biomass.

Growing degree days (GDD) were calculated from daily temperature extremes (Equation 1) recorded at the NWREC weather station, using a mercury thermometer.

$$GDD = \frac{T_{max} - T_{min}}{2} - T_b \qquad \textit{Equation 1}$$

Upper and lower limits to temperature extremes were 30 °C and 10 °C (86 °F and 50 °F), respectively. Cumulative GDD was computed by summation of GDD, commencing from planting date.

Experimental design was randomized complete block, with some restrictions based on distance from the center pivot point. Treatment design was split plot with irrigation capacity (1”/4 days or 1”/8 days) as whole plot treatment and tillage method (NT, ST or CT) as split plot treatment. Population treatments were sampled for LAI and AGB at the mid-level (30,000 seeds/a) only.

Statistical analysis utilized analysis of variance (ANOV), analysis of covariance (ANCOV) and regression techniques (linear and non-linear). Repeated measure of LAI and maximum LAI observed in a year were analyzed by ANOV, using Proc GLM from SAS Institute. Seasonal trends in LAI and AGB were analyzed by ANCOV using third order linear terms of cGDD or days after planting (DAP) as covariates. A logistic model was also used to quantify changes in LAI through pollen shed stage, when all leaves were fully expanded. A three parameter form of the logistic equation

$$LAI = \frac{a}{1+e^{b-c*cGDD}} \qquad \textit{Equation 2}$$

was fit to each set of LAI measurements from V6 through R1, for each set of treatment combinations of each year, using the non-linear feature of Statistix v9.1. Coefficients for ‘a’, ‘b’, and ‘c’ terms were subjected to univariate analysis of variance, with year as a sampling environment.

A linearized form of the logistic equation (Equation 3) was also evaluated.

$$LAI = \frac{L_o \cdot L_m}{L_o + (L_m - L_o)e^{-kL_m t}} \qquad \textit{Equation 3}$$

Here, L_o and L_m are initial and maximum leaf area, t represents days following emergence and k is a logistic coefficient for this linearized form (Aiken, 2005).

RESULTS

Canopy formation

Early season canopy formation occurred more rapidly under CT management in 2005, 2006 and 2007, as indicated by greater leaf area index (LAI, Table 1). End of season canopy persistence was favored by NT management in 2005 and 2006, and by ST management in 2007, as indicated by larger LAI values for later samplings. Irrigation capacity affected LAI mid-season (97 DAP, 1098 °Cd) in 2004; and late-season in 2006 (132 DAP, 1453 °Cd). Maximum canopy formation, averaged among tillage treatments was greatest in 2007 (4.80), least in 2005 (3.35) and intermediate in 2004 (4.12) and 2006 (4.30) see Table 1, Figure 1.

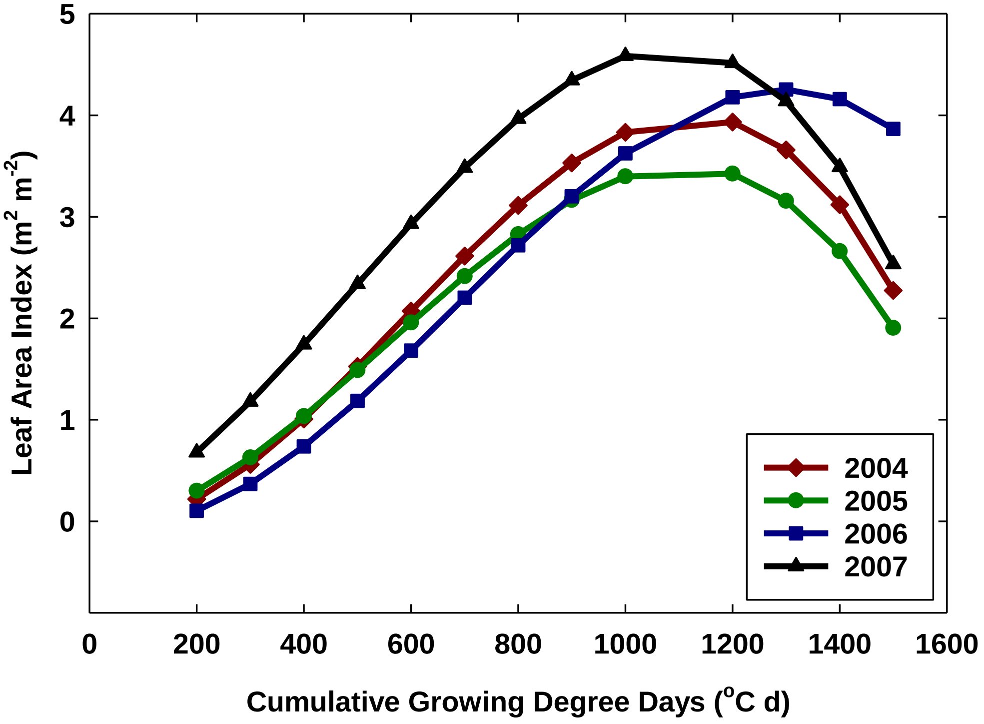

Figure 1. Seasonal trends in leaf area index are shown in relation to cumulative growing degree days after planting, for corn grown in 2004 – 2007 seasons.

Seasonal trends in LAI, averaged over tillage and irrigation capacity effects, indicate delayed LAI development in 2006, relative to the other years (Figure 1). Tillage effects were detected in the 'b' term of the three-term logistic model (Equation 2), when combined for the four years. This term affects the rate of increase in the LAI function, indicating earliest canopy formation for CT (b=6.25), intermediate rate of canopy formation for ST (b=5.61) and latest canopy formation for NT (b=4.96). No significant differences were detected for 'a' (4.16) or 'c' (0.0094) terms, which scale final and initial LAI values, respectively. The linearized form of the logistic equation indicated a negative linear relationship between maximum LAI and the logistic coefficient 'k' (Equation 3, Figure 3). This 'k' term affects the rate of increase in the LAI function of Equation 3, similar to the 'b' term of Equation 2. A smaller 'k' coefficient indicates a slower rate of canopy formation.

Table 1. Leaf area index ($m^2\ m^{-2}$) of corn grown in no till (NT), strip till (ST) or conventional till (CT) management in 2004 – 2007 growing seasons.

Crop year, 2004

Days after planting (DAP)	37	51	65	86	97	110	121	
Cumulative Growing Degree Days (cGDD)	395	506	684	966	1098	1238	1364	
IC 1”/4d	0.60a	1.41a	3.25a	3.58a	**4.49a**	**4.12a**	**2.97a**	
IC 1”/8d	0.55a	1.31a	3.17a	3.58a	**3.75b**	**3.81b**	**2.64b**	
NT	0.56a	1.32a	3.41a	3.51a	4.00a	4.04a	2.79a	
ST	0.62a	1.36a	3.08a	3.63a	4.18a	3.95a	2.90a	
CT	0.55a	1.39a	3.14a	3.62a	4.18a	3.91a	2.74a	

Crop year, 2005

Days after planting (DAP)	50	55	70	83	96	112	126	138
Cumulative Growing Degree Days (cGDD)	377	446	641	818	985	1176	1349	1494
IC 1”/4d	0.71a	0.97a	**2.23b**	3.18a	3.20a	3.38a	2.82a	2.08a
IC 1”/8d	0.77a	1.12a	**2.66a**	3.28a	3.25a	3.31a	2.74a	2.09a
NT	**0.65b**	**0.89b**	2.41a	3.24a	3.18a	3.41a	2.82a	**2.20a**
ST	**0.58b**	**0.96b**	2.32a	3.28a	3.23a	3.34a	2.82a	**2.16ab**
CT	**1.00a**	**1.28a**	2.60a	3.17a	3.26a	3.29a	2.70a	**1.91b**

Crop year, 2006

Days after planting (DAP)	47	61	76	90	104	118	132	147
Cumulative Growing Degree Days (cGDD)	376	558	742	936	1109	1298	1453	1578
IC 1”/4d	0.63a	1.29a	2.37a	4.05a	3.73a	4.40a	**3.72a**	3.88a
IC 1”/8d	0.59a	1.17a	2.39a	3.96a	3.57a	4.20a	**3.25b**	3.60a
NT	0.53a	**1.04b**	2.27a	4.00a	3.87a	4.46a	**3.66a**	3.64a
ST	0.60a	**1.29ab**	2.26a	4.08a	3.55a	4.41a	**3.54ab**	4.00a
CT	0.70a	**1.35a**	2.61a	3.94a	3.52a	4.04a	**3.26b**	3.58a

Crop year, 2007

Days after planting (DAP)	30	44	58	73	87	100	114	132
Cumulative Growing Degree Days (cGDD)	260	4.23	596	790	989	1176	1363	1534
IC 1”/4d	0.30a	1.38a	3.52a	4.65a	4.92a	4.00a	**3.32a**	2.71a
IC 1”/8d	0.31a	1.39a	3.28a	4.65a	4.82a	3.80a	**3.13b**	2.58a
NT	**0.25b**	**1.16b**	3.30a	4.51a	4.75a	**3.77b**	**3.20b**	**2.49b**
ST	**0.27b**	**1.35b**	3.39a	4.61a	4.91a	**4.14a**	**3.44a**	**2.83a**
CT	**0.40a**	**1.64a**	3.51a	4.83a	4.96a	**3.80b**	**3.04b**	**2.62b**

Shaded items, within a column, are significantly different at P<0.05 when followed by a different lower case letter.

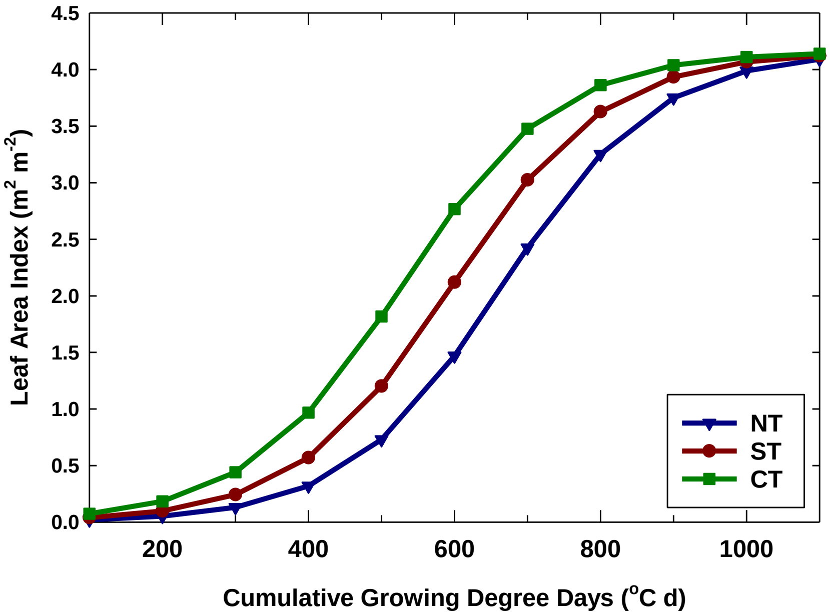

Figure 2. Effects of tillage on seasonal trends in leaf area index are shown in relation to cumulative growing degree days after planting; results are a composite of 2004 – 2007 growing seasons.

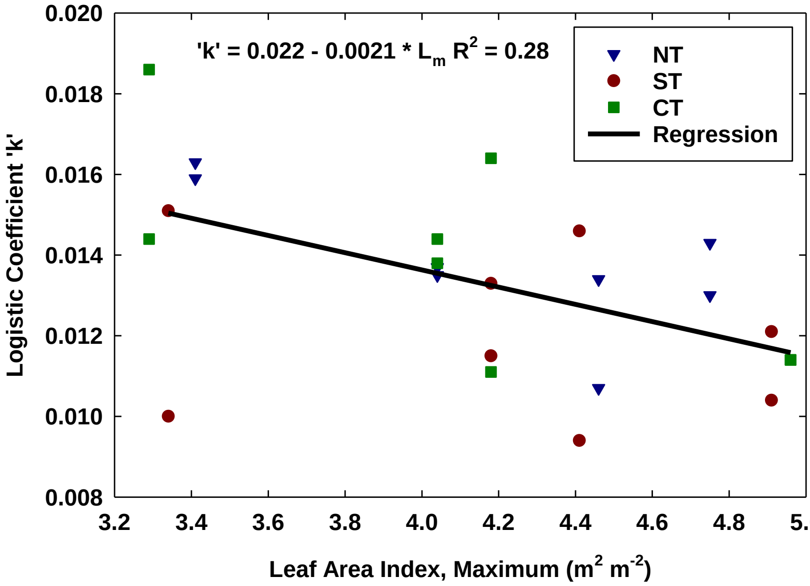

Figure 3. A linear relationship between the linearized logistic coefficient ('k', Equation 3) and maximum leaf area index is shown for corn canopies observed in 2004 – 2007 growing seasons.

Above-ground Biomass

Increased irrigation capacity (1”/4 days) resulted in greater early vegetative growth in 2004 and 2005, greater mid-vegetative growth in all years and greater biomass accumulation at maturity in all years but 2007, as indicated by larger values for AGB (Table 2). Early vegetative AGB accumulation was favored by CT management in 2005, 2006 and 2007, relative to NT management; ST management resulted in similar AGB values to CT management in 2006 and 2007. By tassel formation, AGB was greater under NT management than for CT management in 2004 and 2007; at maturity, in 2004, AGB was greater under ST management than that under CT management. Seasonal trends for AGB accumulation (Figure 4) indicate slightly greater AGB under CT but similar or greater AGB for NT and ST corn by early grain fill stage.

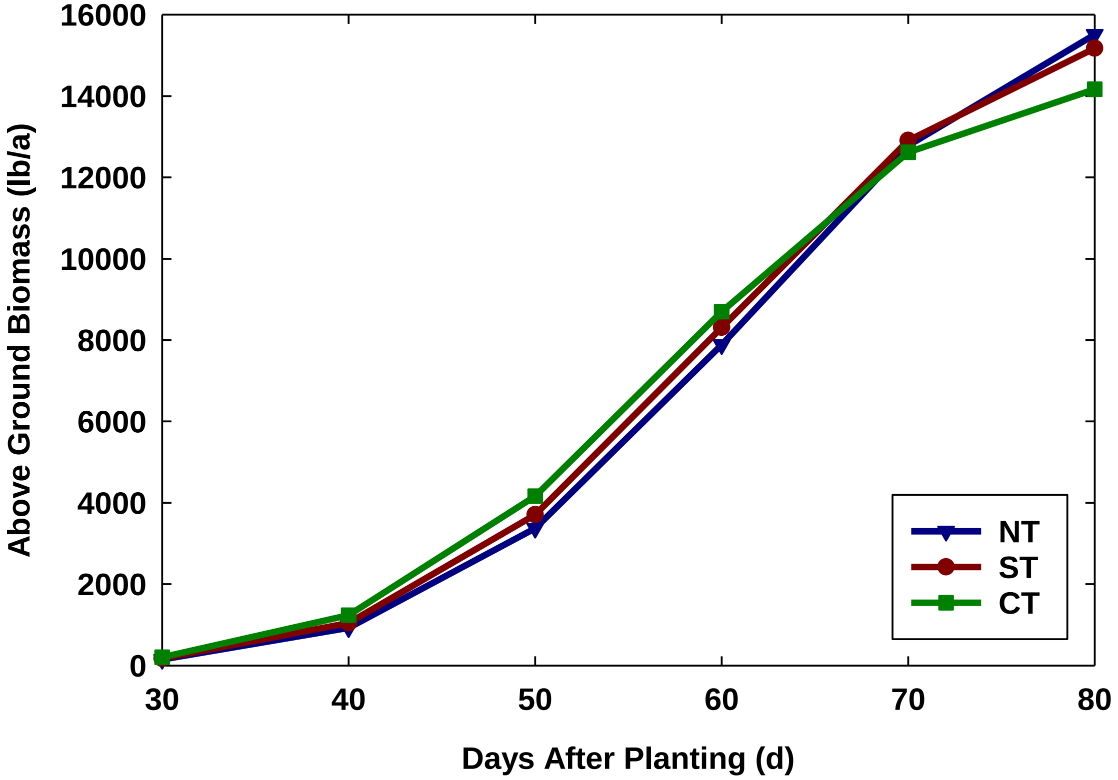

Figure 4. Tillage effects on seasonal trends in apparent above-ground biomass of corn are shown in relation to cumulative growing degree days after planting, for corn grown under no till (NT), strip till (ST) or conventional till (CT) management, derived from 2004 through 2007 growing seasons.

Table 2. Irrigation and tillage effects on above-ground corn biomass, determined by a non-destructive allometric method, is shown for the 2004 – 2007 growing seasons.

Crop year, 2004	**Days after planting (DAP)**					
	36	50	64	82	95	148
	Cumulative Growing Degree Days (cGDD)					
	367	490	652	901	1074	1643
IC 1”/4d	**350a**	**4,160a**	**8,600a**	**11,890a**	12,570a	**31,310a**
IC 1”/8d	**280b**	**3,520b**	**7,780b**	**10,730b**	11,590a	**27,540b**
NT	300a	3,810a	8,120a	**12,160a**	12,550a	**29,380ab**
ST	290a	3,980a	8,540a	**11,400ab**	12,380a	**31,690a**
CT	350a	3,690a	7,890a	**10,400b**	11,330a	**27,270b**

Crop year, 2005	**Days after planting (DAP)**					
	40	54	68	82	95	153
	Cumulative Growing Degree Days (cGDD)					
	282	432	621	804	972	1507
IC 1”/4d	1,210a	4,520a			14,460a	**36,520a**
IC 1”/8d	1,300b	4,720a			13,540a	**31,350b**
NT	**1,170b**	**4,160b**			14,340a	35,370a
ST	**1,180b**	**4,560ab**			13,810a	32,610a
CT	**1,430a**	**5,190a**			13,840a	34,210a

Crop year, 2006	**Days after planting (DAP)**					
	46	60	75	89	102	151
	Cumulative Growing Degree Days (cGDD)					
	364	544	730	921	1079	1622
IC 1”/4d	2,910a	5,930a	12,700a	**13,620a**	**14,510a**	**30,400a**
IC 1”/8d	2,900a	5,640a	12,160a	**12,710b**	**13,450b**	**25,500b**
NT	**2,800b**	**5,210c**	**11,360b**	12,910a	14,170a	27,760a
ST	**2,850b**	**5,780b**	**12,750a**	13,320a	14,100a	29,390a
CT	**3,070a**	**6,420a**	**13,250a**	13,250a	13,660a	26,500a

Crop year, 2007	**Days after planting (DAP)**					
	29	43	57	75	85	132
	Cumulative Growing Degree Days (cGDD)					
	250	403	571	796	928	1504
IC 1”/4d	140a	1,940a	9,830a	19,580a	19,090a	31,230a
IC 1”/8d	140a	1,910a	11,070a	16,320a	17,850a	31,790a
NT	**90b**	**1,400c**	10,270a	19,870a	**20,600a**	31,620a
ST	**160a**	**1,840b**	10,830a	16,590a	**18,990a**	32,260a
CT	**190a**	**2,770a**	10,200a	17,330a	**16,080b**	30,670a

Shaded items, within a column, are significantly different at P<0.05 when followed by a different lower case letter.

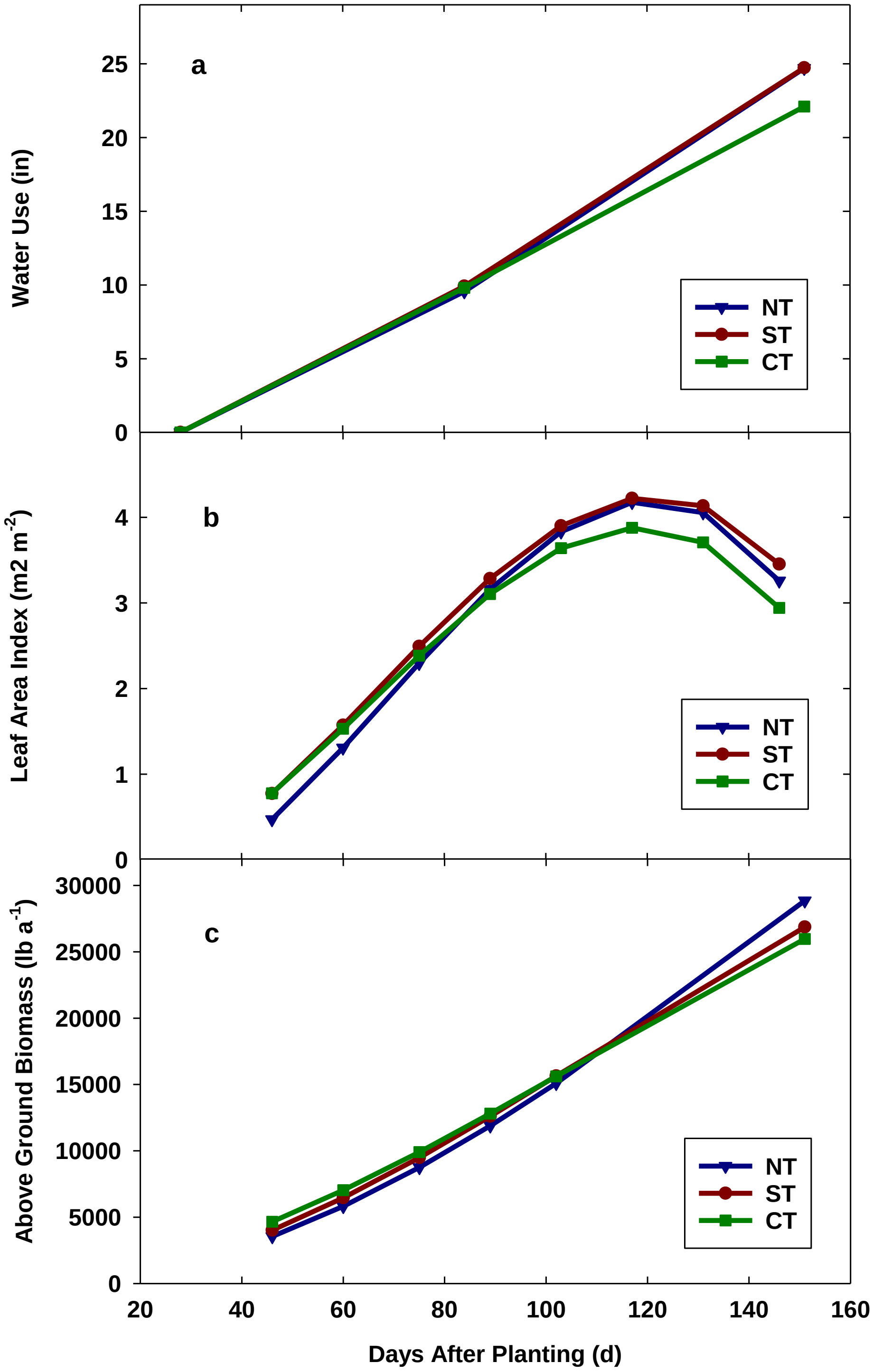

Figure 5. Tillage effects on seasonal trends in crop water use (a), above ground biomass accumulation (b) and canopy formation (c) are shown in relation to days after planting for corn grown under no till (NT), strip till (ST) or conventional till (CT) management in the 2006 growing season; data are taken from the lowest irrigation capacity (1”/eight days).

Early canopy formation and senescence for CT is evident (Fig 5c), with delayed canopy formation for NT; maximum canopy occurred with ST management. Similarly, more AGB accumulated during early vegetative growth under CT management (Fig 5b) with similar AGB for ST by tassel and maximum AGB at maturity for NT. Vegetative crop water use was similar among tillage treatments (Fig 6a), but greater for NT and ST than for CT by maturity, reflecting differences in canopy senescence.

DISCUSSION

Earlier canopy formation and AGB accumulation under CT, detected in three of four years, is consistent with the report of more rapid corn development under CT management in Ontario (Fortin, 1993). This likely results from warmer soil conditions, early emergence, and more vigorous seedling growth under CT management. Earlier canopy senescence and maturity also resulted from CT management in the same three growing seasons, indicating tillage management can cause a 'shift' in canopy formation and senescence.

The delayed canopy formation and extended canopy duration for NT, and, to a lesser extent ST, appears to be related to increased grain yield and increased water use. This could result in extended water use during the late grain fill period, which may not be sufficiently represented in standard crop coefficients used in irrigation scheduling.

Vegetative water use was similar among tillage treatments (an exception, water use was least for NT in 2006, 1"/8 d irrigation capacity). Klocke et al. (2009) reported that virtually 100% residue cover was required to achieve evaporation suppression with incomplete canopy closure. Field observations on April 17, 2007 indicated 80%, 91% and 99% residue cover for CT, ST and NT, respectively. However, greater seasonal water use for ST and NT treatments appear to be associated with delayed canopy senescence and with greater grain yields.

The two forms of the logistic equation (three term and linearized) provide scaling tools with applications to functional representation of corn canopy formation. In this regard, the tillage effect on the three term model provides a useful basis for simulating tillage effects. Similarly, the linearized scaling relationship between LAI max and the 'k' coefficient could be useful for adjusting seasonal LAI values for remote sensing and GIS applications (Maas, 1988; Coyne et al., 2009).

CONCLUSIONS

Reduced tillage delayed corn canopy formation and AGB accumulation during early- to mid-vegetative growth, relative to conventional tillage management, in three of four growing seasons. Delayed canopy senescence was also detected in the same three growing seasons. Greater grain yield and crop water use was associated with this 'shift' in canopy formation. Two forms of the logistic equation provide opportunity to functionally represent tillage effects on corn canopy formation and for use in remote sensing/GIS applications.

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[i] Mention of tradenames is for informational purposes only and does not constitute endorsement by the authors or by the institutions they serve.