

Irrigation and Tillage Management Effects on Canopy Formation in Corn

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Summary

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 in./4 days or 1 in./8 days) and three tillage regimes (no-tillage (NT), strip tillage (ST), or conventional tillage (CT)). Irrigation capacity and tillage effects were evaluated for each sampling period; seasonal trends were evaluated for year and treatment effects. Conventional tillage management resulted in earlier canopy formation and greater AGB accumulation during early vegetative growth in three of four years. No-tillage 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 during 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 suggests 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 ST and NT management, relative to CT 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-inch spaced circular rows on May 8, 2004; April 27, 2005; April 20, 2006; and May 8, 2007. 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 National Oceanic and Atmospheric Administration (NOAA) weather station located approximately 600 yd. northeast of the study site. The reference evapotranspiration (ET_r) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ET_r 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 (Li-Cor, Lincoln, NE). 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 (Li-Cor, Lincoln, NE). 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 Kansas State University Northwest Research and Extension Center weather station, using a mercury thermometer.

$$GDD = \frac{T_{max} - T_{min}}{2} - T_b \quad \text{Equation 1}$$

Upper and lower limits to temperature extremes were 86 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 in./4 days or 1 in./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 included analysis of variance (ANOVA), analysis of covariance (ANCOVA), and regression techniques (linear and non-linear). Repeated measure of LAI and maximum LAI observed in a year were analyzed by ANOVA, using Proc GLM from SAS 9.4 (SAS Institute Inc., Cary, NC). Seasonal trends in LAI and AGB were analyzed by ANCOVA 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 (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 (Analytical Software, Tallahassee, FL). Coefficients for 'a', 'b', and 'c' terms were subjected to univariate analysis of variance, with year as a sampling environment.

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

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

$$LAI = \frac{L_o * L_m}{L_o + (L_m - L_o)e^{-kL_mt}} \quad \text{Equation 3}$$

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, 1976 °Fd) in 2004 and late-season in 2006

(132 DAP, 2615 °Fd). 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) (Table and Figure 1).

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 ($b = 6.25$)¹, 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 and 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.

Above-Ground Biomass

Increased irrigation capacity (1 in./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.

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

¹ Note that 'a', 'b', and 'c' terms were fit in relation to Celsius units for thermal time.

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 in./8 days 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 appears 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 geographic information system (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 opportunities to functionally represent tillage effects on corn canopy formation and for use in remote sensing/GIS applications.

Acknowledgments

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Table 1. Leaf area index (yd² yd⁻²) of corn grown in no-tillage, strip tillage, or conventional tillage management in 2004–2007 growing seasons

		Crop year, 2004							
Days after planting		37	51	65	86	97	110	121	
Cumulative growing degree days (°F d)		711	911	1,231	1,739	1,976	2,228	2,455	
		Leaf area index (yd ² yd ⁻²)							
IC 1 in./4 days		0.60a	1.41a	3.25a	3.58a	4.49a	4.12a	2.97a	
IC 1 in./8 days		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		50	55	70	83	96	112	126	138
Cumulative growing degree days (°F d)		679	803	1,154	1,472	1,773	2,117	2,428	2,689
		Leaf area index (yd ² yd ⁻²)							
IC 1 in./4 days		0.71a	0.97a	2.23b	3.18a	3.20a	3.38a	2.82a	2.08a
IC 1 in./8 days		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		47	61	76	90	104	118	132	147
Cumulative growing degree days (°F d)		677	1,004	1,336	1,685	1,996	2,336	2,615	2,840
		Leaf area index (yd ² yd ⁻²)							
IC 1 in./4 days		0.63a	1.29a	2.37a	4.05a	3.73a	4.40a	3.72a	3.88a
IC 1 in./8 days		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		30	44	58	73	87	100	114	132
Cumulative growing degree days (°F d)		468	761	1,073	1,422	1,780	2,117	2,453	2,761
		Leaf area index (yd ² yd ⁻²)							
IC 1 in./4 days		0.30a	1.38a	3.52a	4.65a	4.92a	4.00a	3.32a	2.71a
IC 1 in./8 days		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. No-tillage (NT), strip tillage (ST), conventional tillage (CT). IC refers to Irrigation Capacity; either 1 in./4 days or 1 in./8 days.

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

Crop year, 2004						
Days after planting	36	50	64	82	95	148
Cumulative growing degree days (°F d)	661	882	1,174	1,622	1,933	2,957
Irrigation and tillage effects						
IC 1 in. /4 days	350a	4,160a	8,600a	11,890a	12,570a	31,310a
IC 1 in. /8 days	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	40	54	68	82	95	153
Cumulative growing degree days (°F d)	508	778	1,118	1,447	1,750	2,713
Irrigation and tillage effects						
IC 1 in. /4 days	1,210a	4,520a			14,460a	36,520a
IC 1 in. /8 days	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	46	60	75	89	102	151
Cumulative growing degree days (°F d)	655	979	1,314	1,658	1,942	2,920
Irrigation and tillage effects						
IC 1 in./4 days	2,910a	5,930a	12,700a	13,620a	14,510a	30,400a
IC 1 in./8 days	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	29	43	57	75	85	132
Cumulative growing degree days (°F d)	450	725	1,028	1,433	1,670	2,707
Irrigation and tillage effects						
IC 1 in./4 days	140a	1,940a	9,830a	19,580a	19,090a	31,230a
IC 1 in./8 days	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. No-tillage (NT), strip tillage (ST), conventional tillage (CT). IC refers to Irrigation Capacity; either 1 in./4 days or 1 in./8 days.

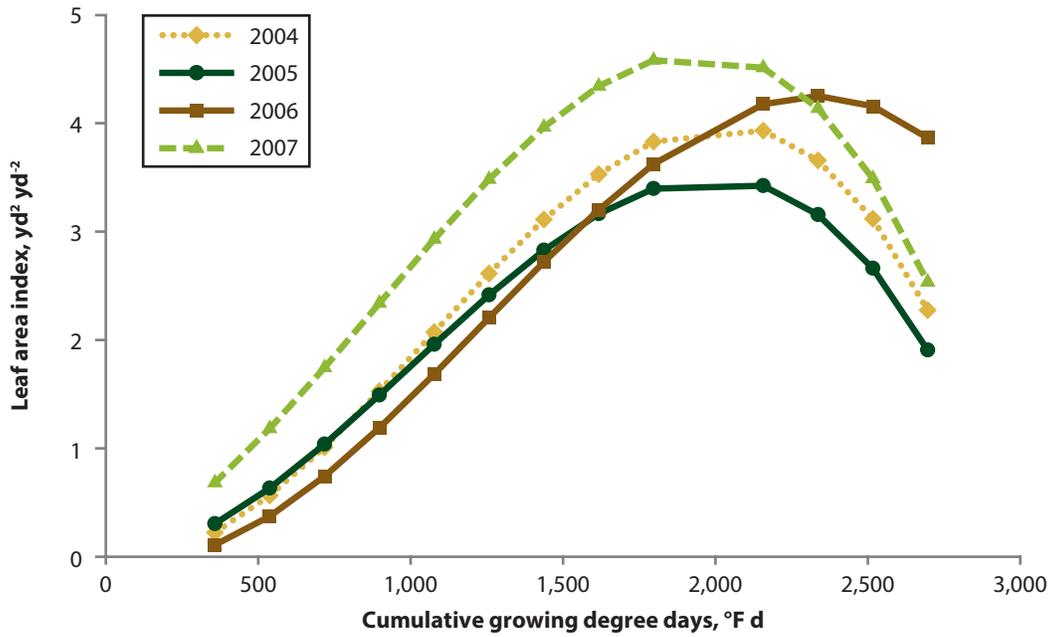


Figure 1. Seasonal trends in leaf area index are shown in relation to cumulative growing degree days after planting, for corn grown in 2004–2007 seasons.

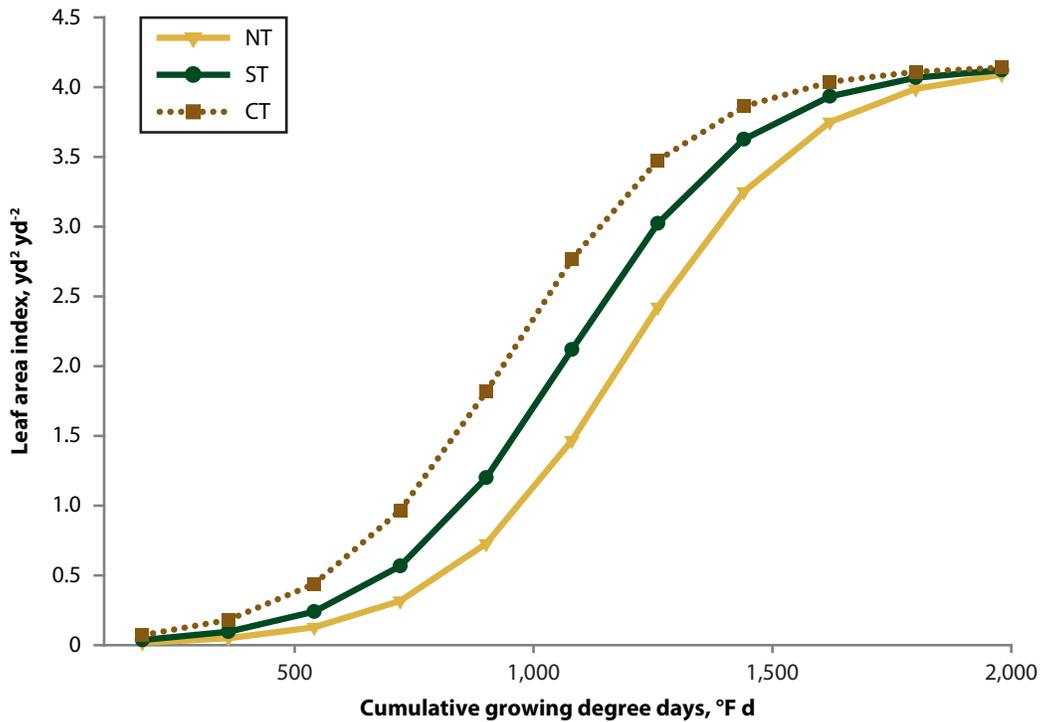


Figure 2. Effects of tillage on seasonal trends in leaf area index are shown in relation to cumulative growing degree days after planting; results are a composite of 2004–2007 growing seasons.

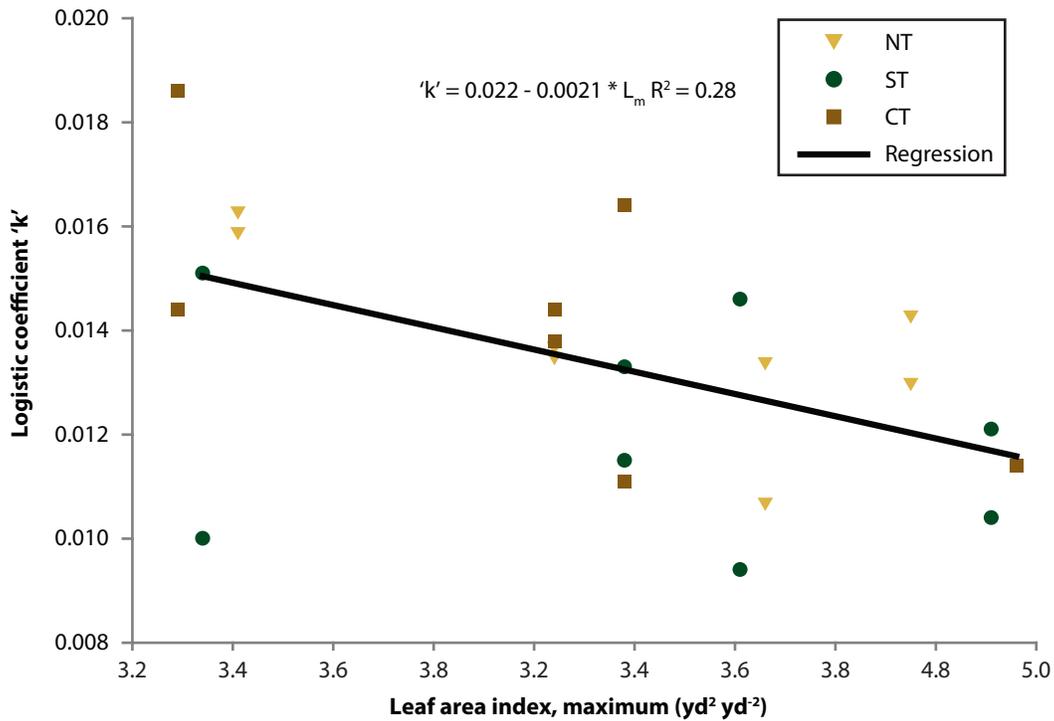


Figure 3. A linear relationship between the linearized logistic coefficient ('k,' Equation 3) and maximum leaf area index is shown for corn canopies observed in 2004–2007 growing seasons.

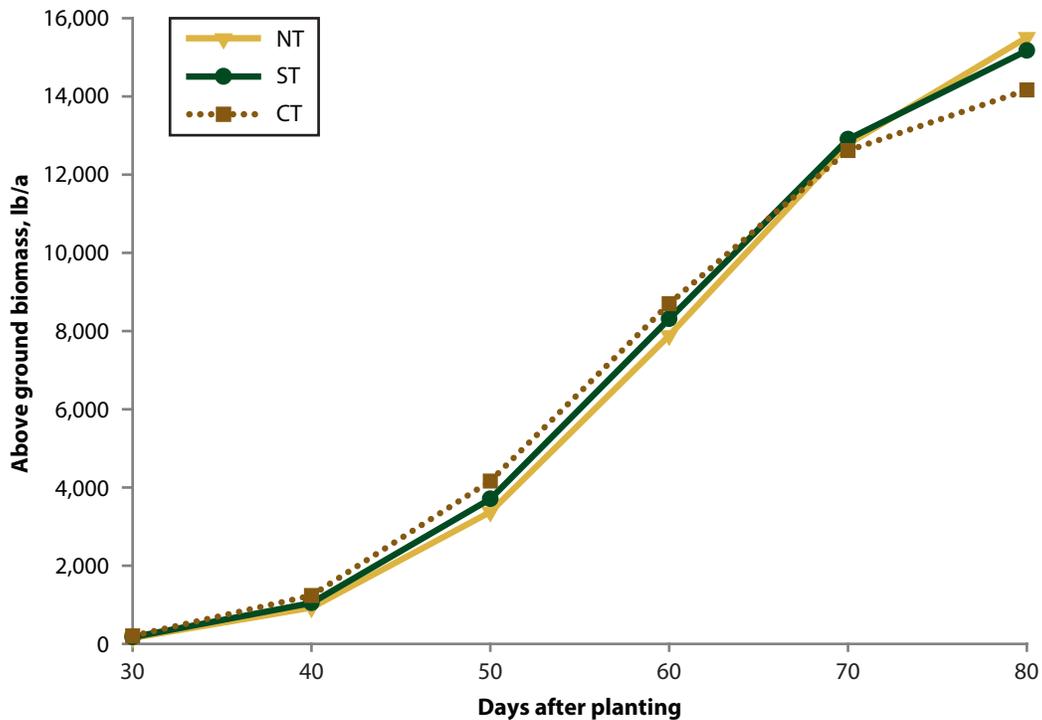


Figure 4. Tillage effects on seasonal trends in apparent above-ground biomass of corn are shown in relation to cumulative growing degree days after planting for corn grown under no-tillage (NT), strip tillage (ST) or conventional tillage (CT) management, derived from the 2004–2007 growing seasons.

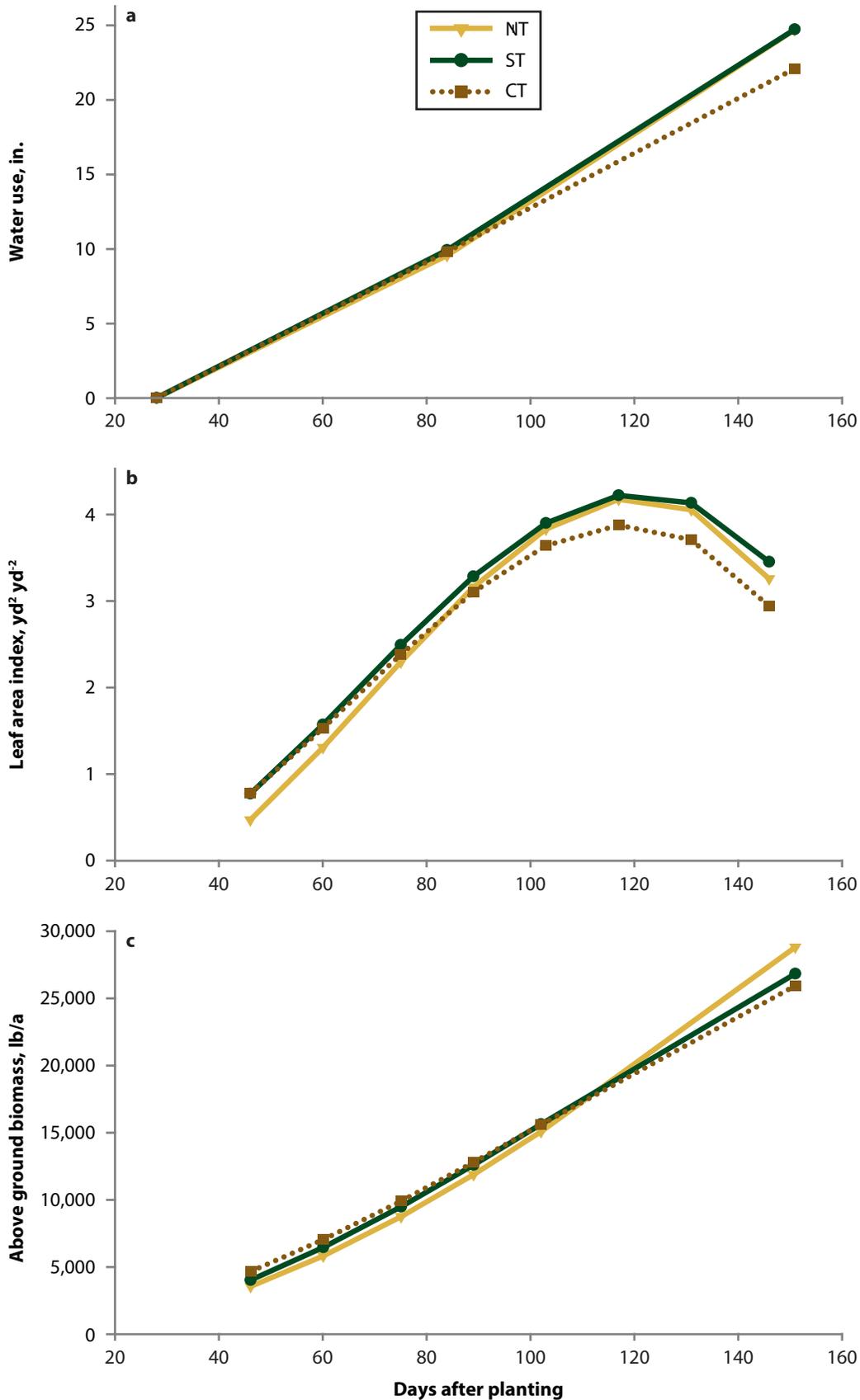


Figure 5. Tillage effects on seasonal trends in crop water use (a), above-ground biomass accumulation (b), and canopy formation (c), are shown in relation to days after planting for corn grown under no-tillage (NT), strip tillage (ST), or conventional tillage (CT) management in the 2006 growing season; data are taken from the lowest irrigation capacity (1 in./8 d).