Agricultural Water Management 160 (2015) 118–131

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Satellite and in situ derived corn and soybean biomass and leaf area index: Response to controlled tile drainage under varying weather conditions

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ARTICLE INFO

Article history:
Received 24 December 2014
Received in revised form 4 June 2015
Accepted 8 June 2015
Available online 28 July 2015

Keywords:
Controlled tile drainage
Uncontrolled Tile drainage
Vegetation indices
Leaf area index
Biomass
Corn
Soybean
RapidEye
Landsat
SPOT

ABSTRACT

Controlled tile drainage (CTD) has environmental and crop production benefits, but the effects of CTD on crop growth under varying weather conditions is not well-documented. This study evaluates the responsiveness of field-scale corn and soybean growth from CTD and uncontrolled tile drainage (UCTD) under varying seasonal temperature and rainfall in eastern Ontario, Canada. Leaf area index (LAI) and total above-ground dry biomass were used as crop growth indicators and were estimated from in situ data and satellite imagery between 2005 to 2013. Corn LAI from CTD fields was maintained or significantly higher relative to the LAI from UCTD fields, in 92% of all site-years; corn biomass from CTD fields was also maintained or significantly higher in all site-years of the study in which it was determined. For soybean, LAI from CTD fields was maintained or significantly higher in 67% of the site-years; biomass from CTD fields was maintained in all site years in which it was determined. Higher water tables and soil water contents, and slightly higher groundwater nitrogen concentrations in CTD fields, may explain these responses. Cohen's *d* effect size of satellite derived LAI ([Mean CTD LAI − mean UCTD LAI]/pooled standard deviation) for corn was negatively related to total May–August precipitation indicating a stronger CTD effect with a decrease in precipitation. In contrast to the corn results, Cohen's *d* of satellite-derived LAI for soybeans was positively related to total May–August (and especially May–July) precipitation, indicating a stronger CTD effect with an increase in precipitation. Results herein could be used to help inform how to optimize the use of growing season CTD for different crops in order to enhance crop growth properties.

1. Introduction

Tile drainage is an important practice for improving agronomic productivity in many landscapes throughout the world. However, from a water and nutrient conservation perspective, tile drainage may only be required during certain times of the year. Controlled tile drainage (CTD) is a practice that regulates tile water loss from fields (Fig. 1). The practice is highly flexible and can be used during the growing season in order to retain water and nutrients in fields for crop growth. Controlled tile drainage has been shown to be effective in reducing pollutant loading to streams, and retaining nutrients and water in fields for crop use (Drury et al., 2009; Sunohara et al., 2015) thereby boosting crop yields (Cicek et al., 2010; Ghane et al., 2012; Ng et al., 2002; Skaggs et al., 2012). The effects of CTD on crop yield are mostly positive (Delbecq et al., 2012; Ghane et al., 2012; Poole et al., 2013; Skaggs et al., 2012; Wesström and Messing, 2007); but some studies have shown insignificant effects of the practice (Cooke and Verma, 2012; Drury et al., 2009), and in a few cases, negative effects (Ghane et al., 2012; Helmers et al., 2012). Crop response to tile drainage water management will be complicated by a vast array of factors including drainage control intensity, physical disposition of tile drainage, soil type, weather, crop type and cropping practice (Cooper et al., 1992; Delbecq et al., 2012; Fraser et al., 2001; Kalita and Kanwar, 1992; Nathanson et al., 1984; Yang et al., 2009; Zhou et al., 2000). Corn (*Zea mays*), for example, is especially susceptible to water and nutrient deficiencies between the vegetative growth stage V12 (corresponds to plant with 12 leaf collars) and the reproductive growth stage R1 (i.e. silking) (Table 1). Soybean (*Glycine max*) becomes more susceptible to extreme weather around the reproductive growth stage R1 (Table 1) when extreme heat (>32 °C) can reduce growth, flow-

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http://dx.doi.org/10.1016/j.agwat.2015.06.007

Table 1
Important development stages for corn and soybean.

Corn	Description	Approximate days after planting	Required CHUs[a]
V12	Vegetative development stage: plant has 12 leaf collars	42	1170
VT	Vegetative development stage: tassel emergence	66	1310
R1	First reproductive development stage: silking	68	1480
Soybean			
R1	First reproductive development stage: beginning bloom	51	700
R4–R6	Reproductive stages R4 to R6 range from full pod (R4) to full seed (R6)	66–76	1230–1850

Summarized from Bagg et al. (2009).
[a] CHUs = Crop heat units.

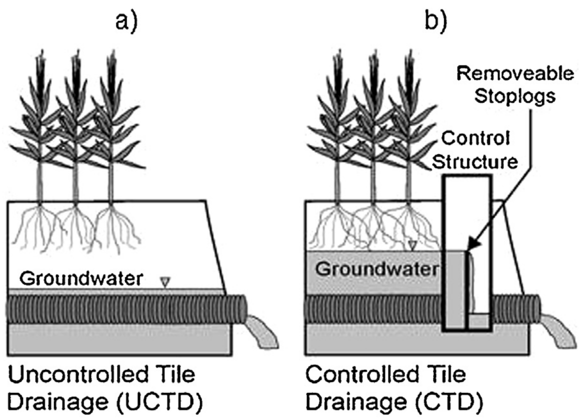

Fig. 1. Uncontrolled tile drainage (UCTD, a) and controlled tile drainage (CTD, b) systems used in this study during the effective growing season.
When water levels are below height of the stoplogs (b), tile flow is fully impeded. When the level is above the height of the stoplogs, tile flow is allowed to occur from field to stream/ditch.

ering, and pod development, and between reproductive growth stages R4 and R6, when water deficiencies can result in significant yield loss (Bagg et al., 2009). And by extension, the impact of retaining/conserving water and nutrients in the field via CTD, will partially depend on the development stage of the crop and the nature of precipitation events (Çakir, 2004; Sionit and Kramer, 1977). A few studies have highlighted the importance of the timing and amount of rainfall for variations in crop yield under CTD management (e.g. Delbecq et al., 2012; Ghane et al., 2012), but no reports were found on the effects of CTD management with respect to crop growth and development under varying growing season weather conditions. Such information can be seen as particularly important for identifying when CTD impact on crop is acute, and for defining how to optimize tile drainage control during the growing season. Moreover, since sub-irrigation is a form of CTD with the added benefit of active irrigation, such information can also help producers to determine when they should sub-irrigate their crops. The research herein was contextualized around such considerations, by using a combination of satellite and field measured data to derive crop growth indicators over multiple years and fields with the objective to evaluate the responsiveness of crop growth to CTD under varying soil hydrological and weather conditions.

The crop growth indicators used in this study were leaf area index (LAI) and above-ground dry biomass. Leaf area, photosynthesis, and biomass are main crop properties/processes affected by water stress (Cavero et al., 2000; Hsiao, 1990), and are indicative of final yield. Crop models (e.g. EPICphase Cabelguenne et al., 1999) often use biomass as an indicator of productivity and calculate yield as the product of the total above-ground dry biomass and the harvest index (the ratio of harvested grain to total above-ground dry biomass, Unkovich et al., 2010). Leaf area is used to characterize the potential of vegetation to intercept photosynthetically active radiation, which makes it an indicator of potential photosynthesis and vegetation growth and health. Studies have suggested that maximum potential yield requires LAI values of at least 3.5–4 m^2/m^2 for soybean (during critical reproductive stages, full bloom to beginning seed, R2–R5: Board et al., 1997; Malone et al., 2002); and at least 5 m^2/m^2 for corn (during critical reproductive stages, tasseling and silking, VT–R1: DeBruin et al., 2013).

The main objectives of this study were: (1) to characterize and examine the effects of CTD on corn and soybean growth (as indicated by LAI and biomass) at field scales between 2005 and 2013, and; (2) to examine the role of rainfall timing and amount, air temperature, and crop heat units on crop response to field scale CTD management.

2. Data and methods

2.1. Study area

The study was located within experimental watersheds in eastern Ontario, Canada (45.26 N, 75.18 W) (Fig. 2). Slopes are predominately <1% and soils are dominated by Bainsville silt loams. The long-term average annual temperature and rainfall are 6.5 °C and 789 mm, respectively. And the long-term average growing season (May–October) temperature and rainfall are 15.8 °C and 536 mm, respectively (Environment Canada, 2014). Corn and soybean are the dominant crops planted in the experimental watersheds, covering ~60% on average (2005–2011) of the crop land (~40% corn, ~20% soybean).

2.2. Study fields, cropping systems, and controlled tile drainage

Details on the CTD system imposed in this study are provided in Sunohara et al. (2014). Briefly, in-line water flow control structures (Agri Drain Corp., Adair, IA, USA) using the stoplog method for restricting flow (Fig. 1), were set to control drainage on fields in the experimental watersheds. The structures were retrofitted to existing tile drainage outlets. Tile drainage systems were gradually installed over the last 40 years. Tile laterals in studied fields are spaced between 15 and 17 m, with a depth of ~1.0 m. Tile laterals drain into a collector or header line that connects to the outlet to stream. The stoplogs within the control structures provide for an adjustable-height system which permits tile drainage only after a desired water level is exceeded (Fig. 1). For this study, as per Sunohara et al. (2014, 2015), the stoplog height was set to 0.60 m below the soil surface from crop planting time to harvest time. Tile drainage was not controlled in the UCTD fields. In both, CTD and UCTD fields, tile drainage was not managed over the winter and early spring for reasons provided in Sunohara et al. (2014, 2015). The experimental approach to assess the effects of tile drainage control on crop growth was built upon the field-pair approach (Cicek et al., 2010; Sunohara et al., 2014). Fields within