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Corn production response to tillage and nitrogen application in dry-land environment

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ABSTRACT

Tillage system and N fertilization management are important factors in corn production. Optimizing these factors can help improve corn production in southeastern Corn Belt under rain-fed environment. A 3-yr study was conducted to determine the effects of three tillage systems (conventional tillage, CT; strip tillage, ST; and no tillage, NT) and five N rates (0, 45, 90, 135, and 180 kg N ha^{-1}) on corn (*Zea mays* L.) plant characteristics at R1 growth stage (the first reproductive stage, silk stage) and grain yield in dryland rain fed environment. Tillage systems had no significant effect on plant height, NO_3–N concentration in plant, and relative chlorophyll content (SPAD) at R1 growth stage, but CT and ST increased normalized difference vegetation index (NDVI) and leaf area index (LAI) at R1 stage compared with NT system. Increasing N rate generally increased plant height (193–209 cm), SPAD (34.8–41.7), NDVI (0.53–0.64), LAI (1.47–1.72) at R1 growth stage and corn grain yield (2.85–4.55 Mg ha^{-1},2.45–4.51 Mg ha^{-1}, and 2.27–3.77 Mg ha^{-1} for CT, ST, and NT, respectively) as N rate did not exceed specific amount. SPAD and NDVI values did not increase with N rates above 90 kg ha^{-1}. The rates above 45, 90, and 90 kg N ha^{-1} did not significantly increase grain yield under CT, ST, and NT system, respectively. There was no statistical difference between CT and ST system for grain yields, and CT and ST generally produced greater yields than NT system. Water availability at corn early reproductive stages significantly influenced corn grain yield. Relatively higher precipitation at corn reproductive stages in 2007 contributed to greater corn grain yields compared with 2008 and 2009 under all these three tillage systems (151 mm, 44 mm, and 54 mm in June, respectively). In 2 out of 3-yr study the ST system contributed to generally higher yields compared to other systems; therefore, it would be a preferable tillage system for planting corn in this area.

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1. Introduction

In Corn Belt, conventional tillage (CT), strip tillage (ST), and no tillage (NT) systems are commonly used in corn production. The CT system generally produces relatively greater corn grain yield with appropriate irrigation and nutrient management compared with NT or ST (Vyn and Raimbault, 1992; Diaz-Zorita, 2000; Vetsch and Randall, 2004), but it may cause nutrient run off and soil erosion (Raczkowski et al., 2009). The NT system is an effective management practice to help conserve water and reduce soil erosion (Halvorson et al., 2001; Raczkowski et al., 2009), and increase soil organic matter (Fabrizzi et al., 2005; Spargo et al., 2008). However, it may lead to excess of residue accumulation and wetter and cooler seedbeds (Vetsch and Randall, 2004; Al-Kaisi and Kwaw-Mensah, 2007; Meyer-Aurich et al., 2009), and may reduce yields compared to CT (Vetsch and Randall, 2004; Busscher et al., 2006; Archer et al., 2008). The ST system involves cultivation of a narrow strip in the row area while leaving the inter-row area undisturbed to protect from erosion. Randall et al. (2001) reported similar yields under ST and CT, and lower yields under NT than ST. Other research showed no significant effect of tillages on corn grain yields (Lund et al., 1993; Al-Kaisi and Kwaw-Mensah, 2007). Different results were probably associated with their diverse soil condition, climate environment, crop rotation, and nutrient management. Kapusta et al. (1996) showed that the yield of maize in NT grown on warmer and well drained early season soils in rotation with another crop can be comparable to that obtained under CT or ST practices. Vyn and Raimbault (1992) also showed that differences were not significant between ST and CT or NT treatments on the clay loam soil.

Tillage management alters soil properties and water dynamics in soil (Clapp et al., 2000; Pikul et al., 2001; Fabrizzi et al., 2005), which influence N availability and crop N requirement (Halvorson et al., 2006). Evanylo (1990) found that N use efficiency was higher under CT than NT due to greater net mineralization of N under CT. Halvorson et al. (2006) reported that the amount of total available

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N needed to maximize grain yield under irrigation was 268 and 276 kg N ha^{-1} for NT and CT systems, respectively. A number of optical spectral indices and canopy characteristics have been widely applied to assist with nutrient management. Numerous researchers have shown a correlation between corn N status and chlorophyll (SPAD) values (Varvel et al., 1997; Bullock and Anderson, 1998; Vetsch and Randall, 2004; Ma et al., 2007), or plant normalized difference vegetation index (NDVI) (Shapiro, 1999; Gitelson et al., 2005; Rambo et al., 2010).

In the southeastern plain, these three tillage systems are all utilized by corn producer. Under dryland conditions, with often insufficient rainfall and irrigation not always available for every farmer, N fertilization management and tillage system selection needs to be further evaluated to determine best management practices to optimize corn production. Therefore, our objective was to evaluate the effect of N fertilization on corn plant characteristics and grain yield in rainfed environment under different tillage systems.

2. Materials and methods

2.1. Experimental site

The field research was conducted at Clemson University's Edisto Research and Education Center near Blackville, SC (33°21′N, 81°19′W) from 2007 to 2009. Soil was classified as Dothan loamy sand (fine loamy, kaolinitic, thermic Plinthic Kandiudult) with average soil pH of 6.2. Initial values of Mehlich I extractable P, K, Mg, and Ca concentrations in the top 15 cm soil were 29, 59, 88, and 325 mg kg^{-1}, respectively. Organic matter in the top 15 cm layer was 16 g kg^{-1}. The study was conducted under dryland rain fed environment. Monthly precipitation and average air temperature during this study are shown in Table 1.

2.2. Experimental design and management

The study was arranged as a split-plot arrangement with four replications. Three tillage systems were main plots and five N rates (0, 45, 90, 135, and 180 kg N ha^{-1}) were subplots. All treatments were arranged in a randomized complete block design. Three tillage systems included conventional tillage (CT), strip tillage (ST), and no tillage (NT). Conventional tillage was performed using disk at 20-cm depth and worksaver (Worksaver, Inc., Litchfield, IL) at about 40 cm depth in the experimental area one day prior to planting. Strip tillage was performed with a seedbed preparation implement, which consisted of in-row subsoil shanks, multiple coulters, and ground-driven crumblers that tilled soil in a band of about 30-cm wide and 35 cm deep. No tillage plot was only disturbed by a four-row no tillage planter at planting time. The N application consisted of applying 35 kg N ha^{-1} at planting

Table 1
Average monthly air temperature and total precipitation during corn growing season at Edisto REC, Blackville, SC, 2007–2009.

Year	Month					
	March	April	May	June	July	August
	Temperature (°C)					
2007	14.7	16.5	20.9	24.6	25.1	27.2
2008	13.0	16.5	21.0	26.4	25.6	25.2
2009	12.8	16.8	21.4	25.9	25.3	25.7
20-yr. average	16.4	17.6	21.7	25.2	26.7	25.9
	Precipitation (mm)					
2007	49	99	14	151	113	70
2008	72	63	76	44	146	161
2009	85	137	284	54	147	24
20-yr. average	106	80	88	129	130	123

(excluding plots without N application) and the remaining N was applied to corn in selected plots at V6 growth stage. The liquid N, in the form of urea-ammonium sulfate (25–0–0–3.5 of N–P_2O_5–K_2O–S), was applied to corn using a Reddick 4-row fertilizer applicator (Reddick Equip. Co., Inc., Williamson, NC). Each plot was 3.9 m wide by 6.1 m long. Each tillage treatment remained on the same plot for the duration of the study.

Cover crop, winter wheat (*Triticum aestivum* L.), was planted in each tillage treatment on 8 December 2006, 21 November 2007, and 26 November 2008, and killed by spraying glyphosate at a rate of 1.1 kg a.i. ha^{-1} on 26 February 2007 and 6 March in 2008 and 2009. Pioneer 31G65 corn (Pioneer Hi-Bred International Inc., Johnston, IA) was planted at 69,200 seeds ha^{-1} and 0.97 m row spacing using a John Deere MaxEmerge vacuum planter (John Deere Co., Moline, IL) on 13, 18, and 23 March in 2007, 2008, and 2009, respectively. During corn growing season, weed control was based on the South Carolina Extension recommendations.

2.3. Plant measurements and analysis

Plant measurements included height, NO_3–N concentration in plant, relative leaf chlorophyll (SPAD) content, normalized difference vegetation index (NDVI), leaf area index (LAI), and corn grain yield. Corn growth, between V6 and R1 stages, was reported as an important period due to a strong relationship between canopy characteristics and corn grain yield (Raun et al., 2005; Teal et al., 2006). In this study, R1 growth stage was selected to evaluate corn plant characteristics. Plant height was determined based on at least ten plants at R1 growth stage. Plant height was measured from the ground to the tip of the tassel. Corn plant samples were collected from all treatments at R1 stage for nitrate-N analyses. Relative chlorophyll (SPAD) content was measured in corn leaves with Minolta SPAD-520 m (Konica Minolta Sensing, Inc., Japan). The chlorophyll (SPAD) meter readings were recorded in ear leaves at R1 stage from 10 plants in each plot. Plant NDVI was measured in two center rows and above each row at R1 stage using the GreenSeeker™ hand held optical sensing instrument (NTech Industries, Inc., Ukiah, CA) and calculated based on the NIR and red reflectance (Tucker, 1979). Leaf area index (LAI) was measured on the 3.0 m long two adjacent center rows using LAI-2000 (Li-Cor, Lincoln, NE). Corn grain was harvested from the entire length of two center rows by hand on 29 and 30 August in 2007 and using an Almaco plot combine (Almaco, Nevada, IA) on 22 and 18 August in 2008 and 2009, respectively. Grain moisture was measured using the Burrows Model MC750 Digital Moisture Computer (Seedburo Equip. Co., Chicago, IL) and grain yield was adjusted to 155 g kg^{-1} moisture content.

The study design was a randomized complete block with a split-plot arrangement. The effects of tillage systems and N fertilization rate on corn plant height, NO_3–N concentration in corn plant, chlorophyll (SPAD) content, NDVI, LAI, and grain yield were assessed using the PROC GLM procedure of SAS (SAS Institute Inc., 2000). Data were analyzed by year when the interaction with year was significant. Means were separated using the least significant difference (LSD). The correlations among corn grain yield and plant variables were accessed using Pearson's correlation coefficients generated by the PROC CORR statement of SAS® (SAS Institute Inc., 2000). The correlation coefficients between grain yield and plant variables provided a basis for deciding their relationship. Treatment effects and interactions were considered significant if $P \leq 0.05$.

3. Results and discussions

3.1. Plant characteristics

There was no interaction of year × tillage × N rate on plant height at R1 growth stage ($P = 0.576$). Plant height was mainly

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