Corn Yield Responses to Plant Height Variability Resulting from Tillage and Crop Rotation Systems in a Long-term Experiment

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17th Triennial Conference of the International Soil Tillage Research Organisation (ISTRO)
Conference Proceedings

Abstract

Tillage and crop rotation system effects on corn (*Zea mays* L.) growth and development have been studied extensively over the past 30 years, but most studies have principally focused on the effects of tillage and crop rotation on mean corn response parameters such as plant height, grain moisture content, and grain yield. As a result, many agronomists and growers have concluded that instances of lower corn yields in no-till versus conventional tillage systems are due to reduced mean plant heights at critical developmental stages in the growing season. However, mean plant heights may not be accurate morphometric indicators of decreased yields in no-till corn. This study, involving portions of a 30 year long-term tillage and rotation experiment, attempted to determine the effects of early-season plant height variability (expressed as coefficient of variation (CV)) versus mean plant heights on yields of a single corn hybrid planted over a 14 year period. The experiment was conducted from 1981-1994 in north-central Indiana on a Chalmers silty clay loam (i.e., a dark prairie soil). The effects of no-till and moldboard plow tillage systems on mean plant height 8 weeks after planting, plant height variability 8 weeks after planting, and grain yield were examined in both continuous corn and corn-soybean rotations. For 10 of the 14 years, the continuous corn, no-till treatment resulted in significantly lower yields relative to the other 3 treatments. The continuous corn, no-till treatment had lower mean plant heights for 11 out of the 12 years when height data at the 8 week stage were available. Plant height variability was numerically greatest for the continuous corn, no-till treatment in 7 out of 12 years of the study; but only significantly higher than one or all other treatments in 5 of those years. Annual yield decreased approximately 122 kg ha^{-1} for each 1% increase in height variability for the no-till plus plow treatment combination in continuous corn. Examination of cumulative precipitation effects revealed that height CV in no-till continuous corn was independent of rainfall quantity accumulated 4 weeks pre- to 4 weeks post-planting, but decreased by 0.30% for each 1 cm increase in rainfall for all other treatments. Weather and other non-treatment factors may also have influenced the degree to which final yields were affected by height CV relative to mean height earlier in the growing season. Nevertheless, our results suggest that increased plant height variability is at least as plausible a factor as lower mean plant heights in being associated with grain yield declines that are common in continuous corn and no-till production systems.

Keywords: No-till; Moldboard plow; Conservation tillage; Continuous corn rotation; Corn-soybean rotation; Mean height; Height CV; Cumulative precipitation

1. Introduction

The use of conservation tillage systems has increased over the past 15 years for most crops grown in the United States as growers search for ways to cut production costs, reduce soil erosion, improve overall soil health, and lessen environmental impacts (Table 1). Yet despite the production, soil, and environmental benefits of conservation tillage practices, the adoption of these systems in corn (*Zea mays* L.) has not increased. In fact, the use of tillage systems in corn leaving greater than 30% residue cover (i.e., no-till, ridge-till, and mulch-till) has steadied or fallen since 1994 (Table 2) (CTIC, 2004). A lack of adoption by growers may have resulted from negative perceptions or experiences associated with corn grown using conservation tillage systems, and in particular no-till practices. These include lower early-season soil temperatures, reduced seed germination, poorer weed control, delayed maturity, decreased plant growth, and lower grain yield potential. Yield reductions have often been observed in no-till systems used on poorly drained, fine-textured soils (Brown et al., 1989; Dick et al., 1991; Vyn and Raimbault, 1993; Opoku et al., 1997), particularly in continuous corn (Chase and Duffy, 1991). In a study in Minnesota by Moncrief et al. (1990, 1991), continuous corn, no-till yields were reduced by 15% compared with continuous corn, fall plow yields on a poorly drained soil. Yet tillage system effects on yield are highly dependent upon soil type, drainage, and climate (i.e., latitude) (Griffith et al., 1973). Past research throughout the United States has shown that no-till corn yields on well drained soils, in more southern latitudes, and with crop rotations are comparable to those obtained using conventional tillage practices (Griffith et al., 1973; Van Doren et al., 1976; Herbek et al., 1986; Dick et al., 1991; Griffith and Wollenhaupt, 1994; Morrison and Chichester, 1994; West et al., 1996).

Table 1
Conservation and other tillage types for all crops in the United States (1990-2004).

(Expressed as percent of total planted acres)								
Conservation Tillage Types (>30% Residue Post-Planting)								
	1990	1992	1994	1996	1998	2000	2002	2004
No-till	6.00%	9.90%	13.70%	14.80%	16.30%	17.50%	19.70%	22.60%
Ridge-till	1.10%	1.20%	1.30%	1.20%	1.20%	1.10%	1.00%	0.80%
Mulch-till*	19.00%	20.20%	20.00%	19.80%	19.70%	18.00%	16.00%	17.40%
Subtotal	26.10%	31.30%	35.00%	35.80%	37.20%	36.60%	36.70%	40.80%
Other Tillage Types (<30% Residue Cover Post-Planting)								
	1990	1992	1994	1996	1998	2000	2002	2004
Reduced-Till	25.30%	25.90%	25.80%	25.80%	26.20%	20.60%	22.80%	21.50%
Conventional-till**	48.70%	42.70%	39.30%	38.50%	36.20%	42.70%	40.60%	37.70%
Subtotal	74.00%	68.60%	65.10%	64.30%	62.40%	63.30%	63.40%	59.20%

*Includes chisel tillage systems **Includes plow tillage systems
Source: Conservation Technology Information Center (CTIC)

As a result of lower yields on poorly drained, fine-textured soils in no-till, continuous corn systems, the effects of a variety of tillage systems on corn growth and development have been studied extensively over the past 30 years using a number of crop rotations. Many previous studies were conducted on a short-term basis (i.e., less than 10 years) (Griffith et al., 1973;

McIsaac et al., 1990; Chase and Duffy, 1991; Wilhelm et al., 2004), and generally neglected to account for variation in weather conditions. However, a number of long-term studies were also performed (i.e., greater than 10 years) (Dick and VanDoren, 1985; Kapusta et al., 1996; West et al., 1996). Most long-term studies have principally focused on the effects of tillage and crop rotation on mean corn response parameters such as plant height, grain moisture content, and yield (Griffith et al., 1988; Kapusta et al., 1996; West et al., 1996; Vyn et al., 2000).

One result of past research emphasizing reduced plant growth and delayed maturity in no-till corn systems (Johnson and Lowery, 1985; Al-Darby and Lowery, 1986; Griffith et al., 1988) is the conclusion among many agronomists and growers that lower corn yields in no-till versus conventional tillage systems are generally associated with reduced mean plant heights at critical developmental stages. Early-season reduced mean plant heights in no-till corn may result from a variety of factors including greater soil residue cover and cooler soil temperatures, both of which can cause delayed plant emergence (Vetsch and Randall, 2002). Griffith et al. (1973), in a study in northern and eastern Indiana, found that as the amount of tillage decreased and percent ground cover increased, plant growth was reduced and maturity was delayed, incidentally resulting in lower early-season mean plant heights.

Table 2
Conservation and other tillage types for corn in the United States (1990-2004).

(Expressed as percent of total planted acres)

Conservation Tillage Types (>30% Residue Post-Planting)								
	1990	1992	1994	1996	1998	2000	2002	2004
No-till	8.49%	13.63%	18.03%	16.83%	16.42%	17.90%	19.11%	19.73%
Ridge-till	2.57%	2.87%	3.09%	2.99%	2.92%	2.10%	1.51%	1.29%
Mulch-till*	21.05%	22.40%	19.30%	20.30%	19.58%	16.46%	15.52%	16.74%
Subtotal	32.12%	38.90%	40.41%	40.12%	38.92%	36.46%	36.14%	37.77%
Other Tillage Types (<30% Residue Cover Post-Planting)								
	1990	1992	1994	1996	1998	2000	2002	2004
Reduced-Till	24.60%	25.23%	23.22%	24.46%	25.08%	23.17%	24.26%	24.56%
Conventional-till**	43.28%	35.87%	36.37%	35.42%	36.00%	40.37%	39.60%	37.67%
Subtotal	67.88%	61.10%	59.59%	59.88%	61.08%	63.54%	63.86%	62.23%

*Includes chisel tillage systems **Includes plow tillage systems
Source: Conservation Technology Information Center (CTIC)

Mean plant heights in no-till systems are not always lower than those in conventional tillage systems since mean plant heights can also be impacted by relative growth rates (Beyaert et al., 2002), moisture availability (Hussain et al., 1999), and fertilizer application (Kapusta et al., 1996) in no-till systems. Nevertheless, no-till plants are often shorter than their conventional tillage counterparts during early growth and development. Even so, mean plant heights (whether during early developmental stages or at physiological maturity) may not be accurate morphometric indicators of decreased yields in no-till corn. Instead, plant height variability in no-till production environments may be a better indicator of no-till yield reductions, since plant height uniformity is associated with greater yields in corn (Glenn and Daynard, 1974).

In a prior study in Indiana, West et al. (1996) found that variable emergence and plant population reductions were more likely in no-till relative to conventional-till plots in some years of their 20 year study. Studies have indicated that emergence variability leads to yield losses in corn (Ford and Hicks, 1992; Liu et al., 2004), as earlier emerging plants out-compete their later emerging neighbors for available resources (e.g., light, water, nutrients) resulting in increased plant height variability (Nafziger et al., 1991; Ford and Hicks, 1992; Pommel et al., 2002; Liu et al., 2004; Tokatlidis and Koutroubas, 2004). Increased stand uniformity may therefore provide potential for yield improvement in corn (Tollenaar and Wu, 1999), particularly that grown in no-till systems. The objective of this 14-year experiment is to determine the effects of early-season plant height variability and mean plant heights on corn yields for various tillage systems and crop rotations. We hypothesize that (a) no-till corn yield reductions are greatest when plant height variability is high, and (b) early-season plant height variability is a more accurate indicator or predictor of corn yield response to tillage and crop rotation than early-season mean plant heights.

2. Materials and Methods

2.1. Site description and experimental design

A long-term tillage and rotation experiment was initiated at the Purdue University Agronomy Center for Research and Education (ACRE) near West Lafayette, IN (40° 28′ N Lat.) in 1975. The soil, which had developed under prairie vegetation, was a Chalmers (fine-silty, mixed, mesic Typic Endoaquoll) silty clay loam with approximately 4.0% organic matter content in the top 30 cm of the soil profile. The experimental area had less than 2% slope and was systematically tile drained at 20 m intervals.

The effects of mean plant heights and plant height variability on mean corn grain yields were analyzed using a subset of 14 years (1981-1994) of data from a dataset spanning 30 years (1975-2004). The experiment was arranged as a split-plot, split-block design composed of four blocks, with crop rotation, tillage system, and year serving as the whole unit, subunit, and split-block, respectively. Each plot was 9.14 m wide (12 corn rows) and 46 m long.

2.2. Treatments and cultural practices

During these 14 years, the experiment involved a single corn hybrid (Becks 65X), two crop rotations (corn-soybean and continuous corn), and four tillage systems (no-till, ridge-till, chisel, and plow). The four tillage systems were as follows:

1. Fall moldboard plowing to a 20 cm depth, with one disking and one field cultivation to 10 cm in the spring prior to planting (plow system).
2. Fall chiseling to a 20 cm depth, with one disking and one field cultivation to a 10 cm depth in the spring prior to planting (chisel system).
3. Ridge-till planting on ridge tops following removal of 2 to 5 cm of soil and residue from the ridge in a one-pass tillage-planting operation (ridge-till system).
4. No-till planting with a single fluted or bubble coulter to cut through residue and loosen soil ahead of standard planter units (no-till system).

Throughout the 14 year study, seeds were planted at a rate of 64,500 plants ha^{-1}. Planting dates ranged from April 25 to May 22, with a mean planting date of May 5 (Table 3). Planting occurred on the same day for all plots for each year of the study. Starter fertilizer was applied in a 5 cm by 5 cm band beside the seed furrow. Starter fertilizer applications included nitrogen (N) for all years of the study, and in 1992-1994, the starter N application rate exceeded 35 kg ha^{-1}. N was also applied as anhydrous ammonia as either a pre-plant or side-dress application at rates of at least 190 kg ha^{-1}. Phosphorus (P), potassium (K), and lime were surface-applied as needed, often prior to primary tillage operations in the fall. Burndown herbicides were applied as necessary to control vegetation prior to planting and pre-emergence herbicides were applied at or soon after planting. Post-applied herbicides were applied only when weed escapes were problematic, and some plots required additional hand-weeding to insure weeds did not depress yields. Insecticides were applied at planting for all 14 years to control Western corn rootworm (*Diabrotica virgifera virgifera* LeConte).

Table 3
Planting dates for all 14 years of the study (1981-1994).

Year	Rank Order Year*	Planting Date	Year	Rank Order Year*	Planting Date
1981	5	22-May	1988	2	26-Apr
1982	14	30-Apr	1989	8	25-Apr
1983	3	10-May	1990	11	26-Apr
1984	10	2-May	1991	1	10-May
1985	12	25-Apr	1992	9	5-May
1986	4	29-Apr	1993	7	11-May
1987	6	5-May	1994	13	26-Apr

*Represents the rank of the grand mean of grain yields from all 4 treatments for each year of the study. A higher rank order year indicates a greater annual grand mean grain yield.

2.3. Field measurements

Plant heights were measured at 4 and 8 weeks post-planting by measuring the extended leaf heights of 8 randomly selected plants in each plot. Plant population, grain moisture content, and final yields were also determined. Grain was harvested from the center 4 rows of each 12 row plot using a commercial combine with a 4 row head. Weight and percentage moisture measurements were collected on the combine. Precipitation, temperature, and Growing Degree Day (GDD) values were also recorded. More detailed accounts of similar materials and methods and associated weather information are provided by Griffith et al. (1988), West et al. (1996), and Vyn et al. (2000).

Weather data from the 14 year period was also analyzed to examine the impacts of precipitation, temperature, and GDD values. Precipitation and temperature means were segmented into 4 week intervals as follows: 4 weeks pre-planting to planting, planting to 4 weeks post-planting, 4 weeks post-planting to 8 weeks post-planting, and 8 weeks post-planting to 12 weeks post-planting.

2.4. Data analysis and statistics

Analysis of Variance (ANOVA) and Regression analyses were conducted using SAS® PROC GLM. Thus far, statistical analyses have only been performed on the no-till and plow systems for both crop rotations since these tillage practices represent tillage “extremes”. Additionally, only 8 week plant height measurements and their relation to yield have been statistically examined thus far. For the statistical analyses, block 1 measurements were omitted due to frequent flooding. Additionally, 8 week plant height measurements were omitted in 1981 and 1987 due to data problems. 8 week plant height coefficient of variation (CV) values were log-transformed prior to ANOVA, and all error terms were pooled (P>0.25) within even- and odd-year analyses. Even- and odd-year analyses were also combined into a single 12 or 14 year model since the even- and odd-year variances were homogeneous.

3. Results and Discussion

3.1. ANOVA Analysis Results:

ANOVA analysis revealed that for 10 years out of the 14 year study, the continuous corn, no-till treatment (CC-NT) had a significantly lower grain yield than the other treatments (i.e., corn-soybean, no-till [CB-NT]; continuous corn, plow [CC-PL]; corn-soybean, plow [CB-PL]) analyzed thus far (Fig. 1). The lower yields observed for the CC-NT treatment have been widely documented in other similar studies across the Midwestern United States (Van Doren et al., 1976; Moncrief et al., 1990, 1991; Chase and Duffy, 1991; Pedersen and Lauer, 2003). West et al. (1996), analyzing the same dataset from which the yield and height data for this study were determined, found that no-till corn had a greater positive response to crop rotation than plow corn. For the 14 years analyzed, CC-NT yields varied tremendously relative to the yields of the other 3 treatments. The lower, relatively variable yields of the CC-NT treatment may be due to reduced plant populations in 1989 (i.e., rank order year 8) and 1994 (i.e., rank order year 13) (West et al., 1996), but plant populations were not significantly lower in the other 12 years of the study (data not presented). Other possible factors contributing to the lower, relatively variable yields of the CC-NT treatment include lower soil temperature (Griffith et al., 1992), delayed root development (Mackay et al., 1985), increased soil strength in previous wheel tracks (Larney and Kladivko, 1989), corn root disease (Tiarks, 1977), and temporal, antagonistic, soil microorganism buildup (Nakatsu et al., 2000). Studies have indicated that no single soil factor is typically responsible for the depressed yields of continuous corn grown under a no-till system (Vyn et al., 2000).

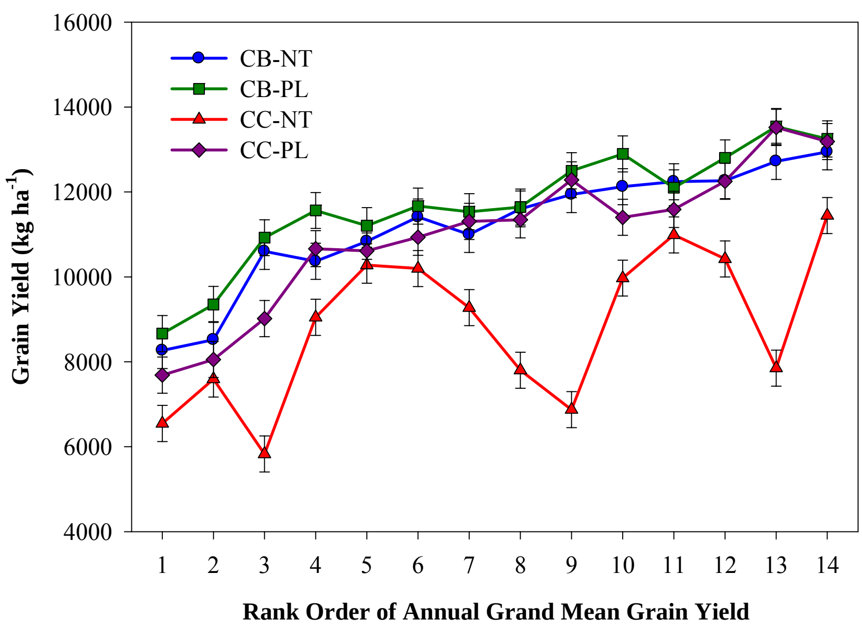

Fig. 1. Annual grain yields for each rotation-tillage treatment for all 14 years of the study (1981-1994). The years are ranked according to the grand mean of grain yields from all 4 treatments. Error bars equal one-half of the least significant difference (LSD) at probability level 0.05. Means are significantly different where error bars do not overlap.

For nearly all 14 years, the yields of the CB-NT, CC-PL, and CB-PL treatments did not differ significantly from one another. Yields for the CC-PL treatment were significantly less than those of the CB-PL treatment in 5 years and yields for the CC-NT treatment were significantly less than those of the CB-NT treatment in 13 years of the study. Yields were 19% lower for CC-NT relative to CC-PL, 4% lower for CB-NT relative to CB-PL, and 12% lower for the CB+CC-NT treatment combination relative to the CB+CC-PL treatment combination (Table 4). The greater yields of the CB-NT treatment relative to the CC-NT treatment are in agreement with numerous other studies (Dick et al., 1991; West et al., 1996; Vyn et al., 2000; Vetsch and Randall, 2002), which found that no-till corn yields were comparable to conventional tillage yields when grown in rotation with soybeans. The recommendation of rotating corn with other crops in no-till systems has existed for nearly 30 years (Van Doren et al., 1976).

Table 4
Yields, mean heights, and average height CVs for the no-till system relative to the plow system for either 12 or 14 years* of the study.

Crop Rotation	**Relative Grain Yield**	**Relative 8 Week Plant Height Mean**	**Relative 8 Week Plant Height CV**
CB+CC	88%	88%	110%
CB	96%	97%	105%
CC	81%	79%	114%

*Relative yield values were calculated using all 14 years of the study (1981-1994), while relative mean height and height CV values were calculated using 12 years of the study (1982-1986, 1988-1994).

The CC-NT treatment, besides achieving lower yields for most years of the study relative to the other 3 treatments, displayed significantly lower 8 week plant height means for 11 out of the 12 years analyzed (Fig. 2). Mean heights were 21% lower for CC-NT relative to the CC-PL, 3% lower for CB-NT relative to CB-PL, and 12% lower for the CB+CC-NT treatment combination relative to CB+CC-PL treatment combination (Table 4). Mean heights did not consistently differ from each other among the CB-NT, CC-PL, and CB-PL treatments, and mean heights for these treatments were nearly identical in the 4 lowest yielding years. However, the mean heights of the CC-NT treatment were consistently shorter and varied largely relative to the mean heights of the other 3 treatments for the 8 highest yielding years. The reduced mean heights of the CC-NT treatment are consistent with the results of the first 12 years (Griffith et al., 1988) and the first 20 years (West et al., 1996) of the experiment from which the current 12-year data was extrapolated. Griffith et al. (1988) found that at 8 weeks after planting, no-till, continuous corn was 25 cm shorter and no-till corn in a corn-soybean rotation was 7 cm shorter than corn grown under conventional tillage practices. West et al. (1996) observed that average no-till, continuous corn growth (expressed as mean plant height 8 weeks after planting) was suppressed by 17%, and that mean heights were similar among tillage systems in the corn-soybean rotation. Years with the lowest 8 week plant height means did not necessarily coordinate with years displaying the lowest yields for the CC-NT treatment, although the 2 measures did appear to follow similar trends for the 8 highest yielding years (Figs. 1 and 2).

Plant height CVs at 8 weeks were numerically greatest for the CC-NT treatment in 7 out of 12 years of the study; however, in only 2 of those years were the height CVs for the CC-NT treatment significantly higher than those of all other treatments (Fig. 3). The CC-NT treatment also displayed significantly greater height CVs than the CC-PL treatment for 2 years, than the CB-PL treatment for 5 years, and than the CB-NT treatment for 4 years of the study. Height CVs averaged 14% greater for CC-NT relative to CC-PL, 5% greater for the CB-NT relative to CB-PL, and 10% greater for the CB+CC-NT treatment combination relative to the CB+CC-PL treatment combination (Table 4). Height CVs for each treatment did not follow any particular trend relative to the other treatments. Although there was a tendency for lower yields when height CVs increased, the years with the greatest height CVs did not necessarily correspond to the years with the lowest yields (Figures 1 and 3). Additionally, the years with the greatest height CVs (i.e., years 2, 8, and 13) generally displayed the lowest mean heights; however, not every year displayed this pattern (Figures 2 and 3).

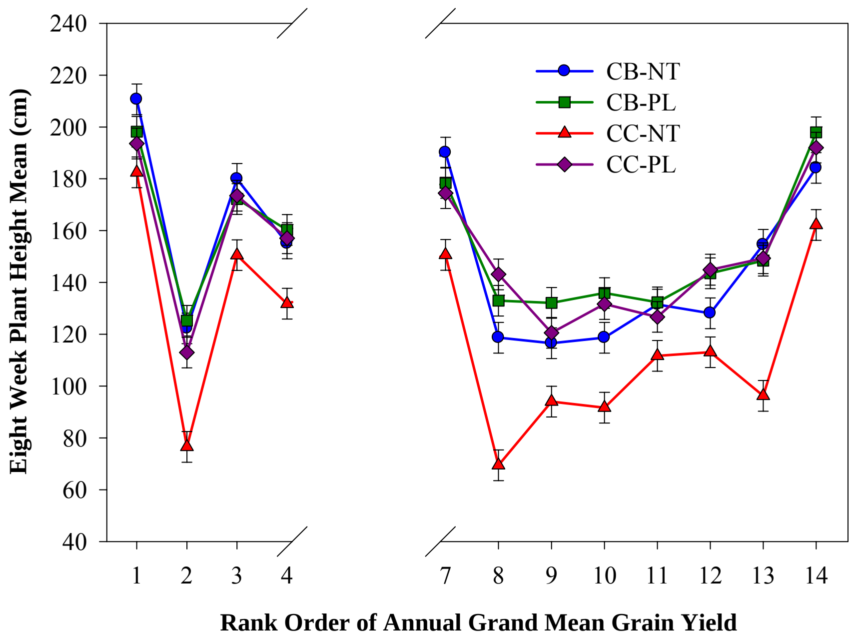

Fig. 2. 8 week plant height means for each rotation-tillage treatment for 12 years of the study (1982-1986, 1988-1994). The years are ranked according to the grand mean of grain yields from all 4 treatments. Error bars equal one-half of the least significant difference (LSD) at probability level 0.05. Means are significantly different where error bars do not overlap.

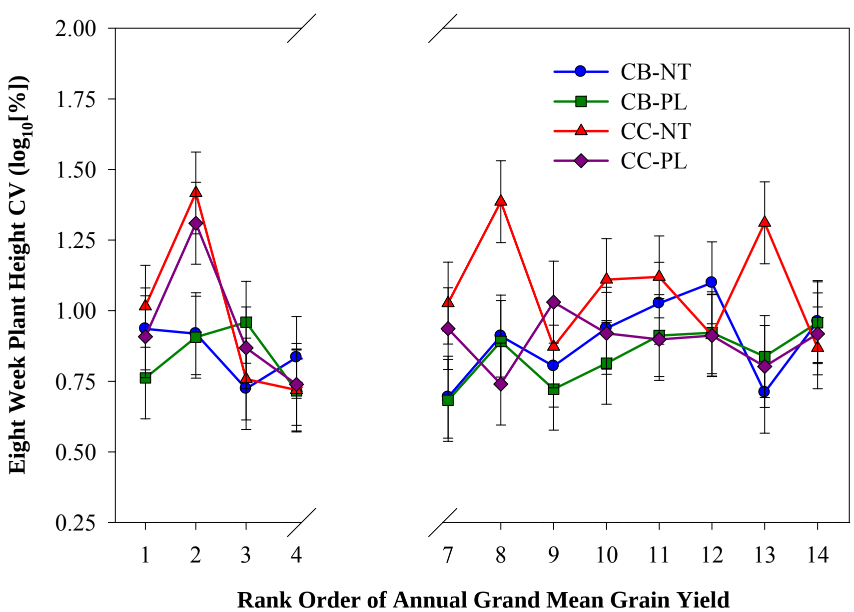

Fig. 3. 8 week plant height CVs (log_{10}[%]) for each rotation-tillage treatment for 12 years of the study (1982-1986, 1988-1994). The years are ranked according to the grand mean of grain yields from all 4 treatments. Error bars equal one-half of the least significant difference (LSD) at probability level 0.05. Means are significantly different where error bars do not overlap.

3.2. Regression Analysis Results:

Regression analysis over 12 years of the 14 year study showed that grain yield was not influenced by the 8 week plant height means for all treatments except CC-NT, for which yield decreased approximately 23 kg ha^{-1} for each 1 cm increase in mean height (Fig. 4). The association between decreasing yield and increasing mean height for the CC-NT treatment is difficult to explain, but the two lowest yielding years may have significantly affected the slope of the regression line for the CC-NT treatment. If these 2 years were eliminated, the association between yield and mean height would be positive.

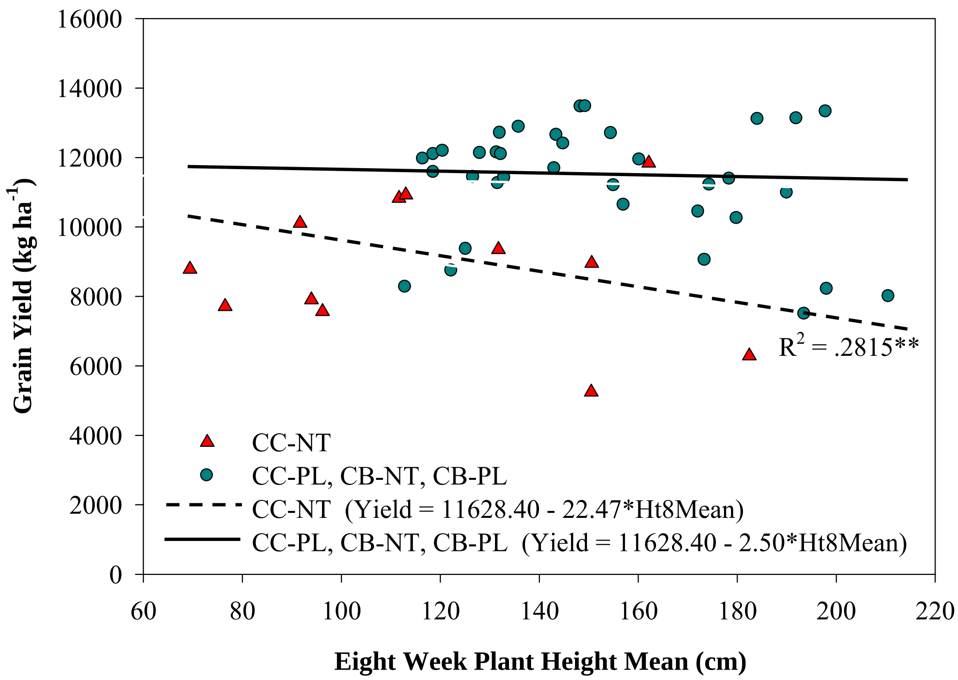

Fig. 4. Relationship between annual grain yield and 8 week plant height mean for 12 years of the study.

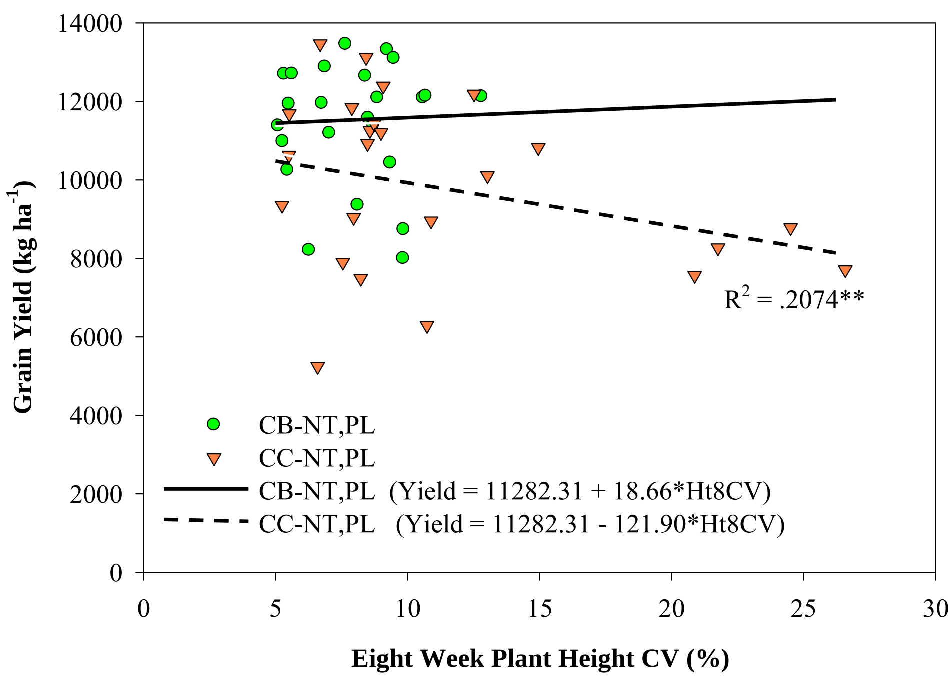

Fig. 5. Relationship between annual grain yield and 8 week plant height CV for 12 years of the study.

Analysis over 12 of 14 years showed that grain yield decreased approximately 122 kg ha^{-1} for each 1% increase in 8 week plant height CV for the CC-NT,PL treatment combination (Fig. 5). Furthermore, the largest height CVs were associated with predicted yields of approximately 9,100 kg ha^{-1} or less. However, yields were not influenced by height CV for either the corn-soybean or the continuous corn rotation when consideration was limited to height CVs less than 16%.

Cumulative rainfall effects upon 8 week plant height CVs and subsequent yields revealed that height CV was not influenced by the amount of rainfall accumulated 4 weeks pre- to 4 weeks post-planting for the CC-NT treatment. However, 8 week plant height CVs decreased by 0.30% for each 1 cm increase in rainfall accumulated 4 weeks pre- to 4 weeks post-planting for all other treatments. Further exploratory analysis revealed that the relationship (i.e., slope of the regression line) for the CC-NT treatment remained the same when height CVs greater than 20% (i.e., potential outliers) were omitted, suggesting that the 3 highest CV values did not alter or skew the regression relationship for the CC-NT treatment.

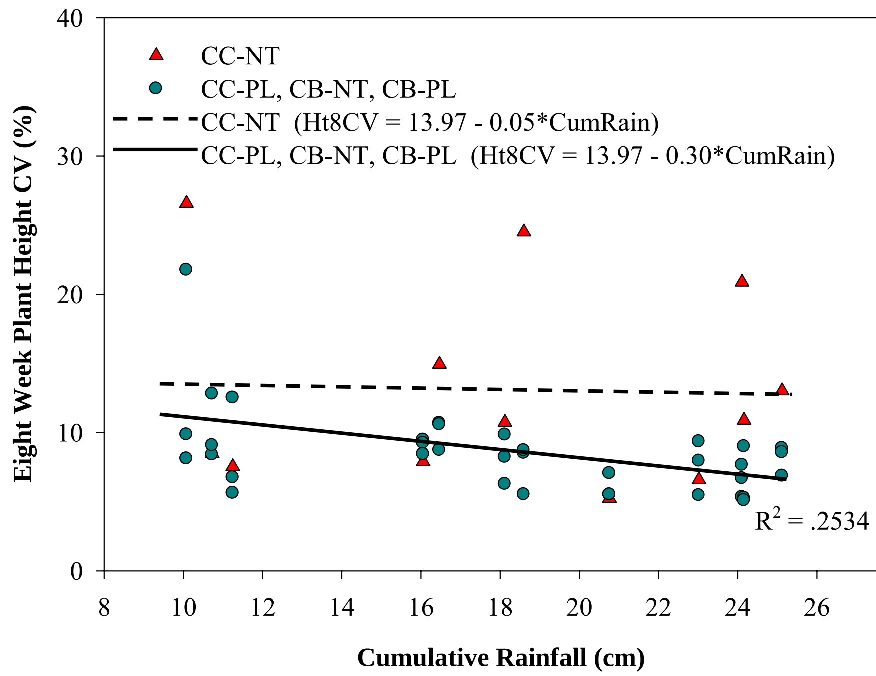

Fig. 6. Relationship between 8 week plant height CV and cumulative rainfall for 12 years of the study. Cumulative rainfall represents total rainfall accumulated from 4 weeks pre- to 4 weeks post-planting.

4. Conclusions

The lower grain yields of the CC-NT treatment observed for a majority of the years in this study have been reported extensively in the past (Moncrief et al., 1990, 1991; Chase and Duffy, 1991). Yet the year-to-year variability of no-till, continuous corn yields and its respective causes has not been as frequently investigated on a long-term basis. Throughout this 14 year study, the yields of the CC-NT treatment were highly variable regardless of the grand mean grain yield level. This enhanced variability may have been due to a variety of causes, many of which were likely associated with weather-related phenomena that directly impacted early-season corn growth and development. In a 7 year study by Swan et al. (1994) in which the effects of residue level on long-term, no-till, continuous corn were examined, the authors found that seasonal effects (i.e., weather conditions) accounted for >90% of the variability in grain yield across the 7 years. Non-weather factors such as poor weed control and improper seed placement can also contribute to lower no-till corn yields (Swan et al., 1994), but consistent weed control throughout this trial essentially assured that yield differences were not due to weed pressure. The yields of the CC-PL treatment were both greater and less variable than those of the CC-NT treatment, suggesting that crop rotation may have had a greater impact upon yield than tillage practice. Nevertheless, the treatment combination of no-till and continuous cropping may have been the cause of lower, highly variable yields for the CC-NT treatment, as this system creates a complex association of soil and surface conditions that both directly and indirectly influence the performance of corn (Wilhelm et al., 2004).

The significantly lower 8 week plant height means of the CC-NT treatment for nearly every year suggest that the CC-NT treatment significantly impeded corn growth during the first 8 weeks of development. While reduced residue removal in no-till systems improves soil aggregation (Tisdall and Oades, 1982), soil organic matter content (SOM) (Wilhelm et al., 2004), and overall soil tilth (Carter, 2002), it can also significantly impede corn growth, especially of later-maturing hybrids (Carter and Barnett, 1987). Interestingly, the year with the lowest grand mean grain yield (i.e., rank order year 1) exhibited among the greatest mean heights for each treatment. Yet large mean heights for each treatment were also associated with the highest grand mean grain yield (i.e., rank order year 14). These opposing relationships confirm that large mean heights at a fixed time after planting may not always indicate or predict high corn yields. Earlier planting dates (i.e., earlier than April 28) were associated with years exhibiting reduced mean heights (e.g., rank order years 2, 13, and 14) while later planting dates (i.e., later than April 28) were associated with years exhibiting greater mean heights (e.g., rank order years 1, 3, and 7). The association between early planting and reduced mean heights was also observed by Nafziger et al. (1991), although only reductions in final mean heights were considered in their study. Time of planting may therefore have affected both 8 week plant height means and yields, although the effect of time of planting in relation to soil temperature, GDD accumulation, and precipitation must be further examined.

The CC-NT treatment displayed significantly greater 8 week plant height CVs than all other treatments in only 2 years of the study; however, CC-NT height CVs were numerically greatest in 7 out of 12 years analyzed. The CC-NT treatment also displayed significantly greater height CVs than the CC-PL treatment for 2 years, and greater height CVs than both the CB-PL and CB-NT treatments in 4 years of the study. The 3 years with the greatest height CVs (i.e., rank order years 2, 8, and 13) for the CC-NT treatment also possessed the greatest mean heights, suggesting that factors which influenced mean heights during these years also may have affected height variability. Yet these 3 years were not the lowest yielding years, suggesting that neither early-season mean plant heights nor plant height variability themselves perfectly indicated or predicted low yielding years.

The relationship between grain yield and 8 week plant height CV was moderately negative for the CC-NT,PL treatment combination yet slightly positive for the CB-NT,PL treatment combination, showing that yield declined with increasing height CV in continuous corn but not in the corn-soybean rotation. The negative relationship of the CC-NT,PL treatment combination was highly affected by the 4 years with the greatest height CVs. As with 8 week plant height means, further analysis of these “extreme” years with respect to temperature and precipitation is necessary before correlated or causal factors can be determined.

An increase in cumulative rainfall 4 weeks pre- to 4 weeks post-planting was associated with a decrease in 8 week plant height CV for the CC-PL, CB-NT, and CB-PL treatments, but not for the CC-NT treatment. This relationship suggests that factors other than precipitation may have contributed more to no-till, continuous corn plant height variability. Factors including variable residue cover and soil temperature, non-uniform seed depth (Ford and Hicks, 1992), and uneven corn emergence (Nafziger et al., 1991) have been implicated in grain yield reductions, and may have possibly been associated with plant height variability in this study.

In a long-term experiment such as this study, the effects of various tillage systems and crop rotations on early-season plant height variability, mean plant heights, and subsequent grain yields cannot be fully explained without an accompanying in-depth analysis of weather data. Future analysis of corn plant response in these long-term tillage and crop rotation trials will require more understanding of weather-related effects.

In this study, we first investigated the effects of plant height means and CVs on actual yields of the 4 tillage system and rotation treatment combinations over time. Plant height CV may have had more impact on the relative yield differences (for instance, on a percent basis) between tillage treatments within a year, and this aspect will be explored further. Although we had the advantage of a 14 year period with a single genotype, we had a relatively small number of plants (8) per individual plot for our data set. Tillage treatment effects on plant height variability would have been easier to explore with a larger number of measurements. Nevertheless, our results thus far suggest that increased plant height variability is at least as plausible a factor as lower mean plant heights in being associated with (if not responsible for) grain yield declines that commonly occur with continuous corn and no-till production systems.

Acknowledgements

Dr. J.V. Mannering, H. Galloway, and D.R. Griffith initiated this long-term tillage and crop rotation experiment in 1975 and continued to coordinate research at this site until their respective retirements in 1989, 1980, and 1995. Numerous faculty, research agronomists, and graduate students have been involved over the years in various multi-disciplinary research investigations within the long-term tillage research plots.

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