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Soil & Tillage Research 63 (2001) 15–24

Soil & Tillage Research

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Effect of penetration resistance and timing of rain on grain yield of narrow-row corn in a coastal plain loamy sand

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Received 23 October 2000; received in revised form 16 May 2001; accepted 22 June 2001

Abstract

In many soils of the southeastern Coastal Plain of the USA, subsurface hard layers reduce yield by limiting root exploration of the profile. We evaluated the impact of reduced frequency of deep tillage (and thus increased penetration resistance) and timing of rain on corn (*Zea mays* L.) yield for a 0.38 m row-width management system. Treatments were either disced or not disced; treatments were also deep-tilled from 0 to 3 years before sowing corn into a structureless Goldsboro loamy sand, a thermic siliceous fine-loamy Aquic Paleudult (fine-loamy Acrisol). Because of a pan at the 0.1–0.3 m depth, cone indices for disced treatments were greater than for non-disced treatments. Cone indices were also greater for treatments that had longer times between tillage and sowing corn, increasing on an average of about 200 kPa/year. Whether caused by discing or by reduced tillage frequency, each MPa of increased mean profile cone index reduced corn grain yields by 1.1–2.4 Mg/ha. Cone index vs. grain yield linear regressions differed among years. Regressions for the 3 years could be combined into a single relationship by including rainfall during 42–56 days after sowing (vegetative growth) and 70–98 days after sowing (silking) to the relationship ($R^2 = 0.87$). The same procedure was then applied to soybean (*Glycine max* L. Merr.) grown in the same plots for the previous 3 years, giving similar results ($R^2 = 0.73$). When rainfall for the growing season or selected parts of the growing season based on plant maturity is included in the regression relationship of yield as a function of soil cone index, the relationship may be valid for multiple growing seasons eliminating the need to have individual relationships for each season.
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Keywords: Paratill subsoiler; Deep tillage; Loamy sand; Rainfall; Subsoil hardpan; Coastal plain; Penetration resistance

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1. Introduction

Interest in narrow-row corn (*Zea mays* L.) management has increased because of its potential for higher grain yield, for quicker canopy cover, and for using the benefits of herbicide resistant hybrids (Benga et al., 1997; Frederick et al., 1998). In the southeastern USA, higher narrow-row yield is attributed to the overall management system which includes deep tillage (Bauer et al., 2000). This may impact large coastal areas; for example, approximately 0.5 million ha of corn were sown in the southeastern USA in 2000 (USDA-NASS, http://www.fedstats.gov/index20.html).

High soil strength is an impediment to plant growth and high crop yields (Panayiotopoulos et al., 1994; Mapfumo et al., 1998; Masle, 1998; Coelho et al., 2000). In many coastal plain soils, high strength can be found throughout the entire profile, but it is especially

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PII: S0167-1987(01)00228-8

heightened in the E horizon, just below the Ap. Strength in the E horizon has been found to be high enough to restrict root growth, even when soil is at field capacity (Campbell et al., 1974). Cone indices at or above 2 MPa are routinely measured in the E horizon (Sojka et al., 1991) with 2 MPa considered as root limiting (Taylor and Gardner, 1963; Blanchar et al., 1978; Martino and Shaykewich, 1994) for soils of similar textures. Cone indices in these coastal soils, as measured at the beginning of the growing season, have been inversely correlated with yield (Busscher et al., 2000). Soil strengths are also linked to water contents; they increase and decrease as the soil dries and is rewet (Coelho et al., 2000; Busscher et al., 1987).

Reduced soil strength and improved yield can be achieved through deep tillage (Salih et al., 1998; Busscher et al., 2000). In these Coastal Plain soils, although residual effects of deep tillage may be seen for years afterward (Threadgill, 1982; Busscher et al., 1986), deep tillage is recommended annually, either in spring (Threadgill, 1982; Busscher et al., 1986) or fall (Porter and Khalilian, 1995) or perhaps both (Frederick et al., 1998) because incomplete soil reconsolidation between growing seasons is enough to increase soil strength to yield-reducing levels. Effects of deep tillage continue to diminish with time and, after 3 years, effects of deep tillage are no longer evident (Busscher et al., 1995).

High strength problems are compounded by low available soil water content. Although rainfall is abundant in the southeastern Coastal Plain of the USA at 1000–1800 mm annually (http://www.ocs.orst.edu/pub/maps/Precipitation/Total/U.S.), water for plant growth can be limiting. Soils are generally sandy and low in water holding capacity, retaining as little as 80 mm of water per meter of soil depth (Beale et al., 1966). If there is no rainfall for 2 weeks, crop stresses can reduce yields (Sadler and Camp, 1986). Most growing seasons in this region have 2 weeks or longer with no rainfall (Sheridan et al., 1979). Deep tillage helps alleviate plant water stress by making more of the profile available for root exploration and water extraction.

Since the effectiveness of deep tillage decreases with time, our objective was to develop a relationship between corn yield and soil strength for a narrow-row management system. From a previous study (Busscher et al., 2000), we suspected that the relationships would be specific to each growing season. Therefore, a second objective was to use easily accessible rainfall data to develop one regression of yield as a function of soil strength and rainfall from the several regressions of yield as a function of soil strength developed for individual growing seasons.

2. Materials and methods

2.1. Field sites

Between 1993 and 1996, before the present experiment, field plots at Clemson University's Pee Dee Research and Education Center near Florence, SC were sown to wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L. Merr.) double crop, both of which were deep tilled with a Paratill and drilled in 0.19 m-wide rows (Frederick et al., 1998). Between 1997 and 1999, the same plots were used to grow corn. Plots were 3 m wide and 15 m long. Plots were immediately adjacent to one another along their sides, arranged in two lines that were separated by 10 m in the direction of their lengths to accommodate turning of tillage equipment. Plots were located on a Goldsboro loamy sand (a thermic siliceous fine-loamy Aquic Paleudult; a fine-loamy Acrisol) that had an E horizon below the plow layer (Table 1). The experimental site was level.

The corn growing seasons, April–August, for 1997–1999 were drier than usual with rainfalls 13, 11, and 31% below normal, respectively. The corn growing season mean temperatures were 0.6°C cooler than usual for 1997, 1.6°C warmer than usual for 1998, and 1.2°C warmer than usual for 1999 (Table 2). For all 3 years and for the long-term means, potential evapotranspiration was greater than rainfall for the corn growing season (Table 2) and, because of this difference, potential evapotranspiration was greater than rainfall for the whole year.

2.2. Tillage and cropping treatments

The day before corn was sown, two surface tillage and four deep tillage treatments were imposed on the plots. Two surface tillage treatments involved not discing (sowing into the stubble of the previous season's

Table 1
Soil profile information for the Goldsboro series a very deep, moderately permeable, moderately well-drained soil that formed in Coastal Plain sediments

Horizon	Thickness (m)	Texture	Clay (g kg^{-1})	OM (g kg^{-1})	CEC (cmol kg^{-1})
Ap[a]	0.2	Loamy sand	20–80	5–20	1–3
E	0–0.25	Loamy sand	20–80	5–20	1–3
BE	0–0.25	Sandy loam	20–80	5–20	1–3
Bt	To depth of ~0.65	Sandy clay loam	180–300	0–5	2–4

[a] From http://www.statlab.iastate.edu/soils/osd/dat/G/GOLDSBORO.html.

Table 2
Rainfall, temperature, and potential evapotranspiration for the experimental site

Year	Rainfall (mm)	Temperature (°C)	Potential evapotranspiration[b] (mm)
Corn growing season[a]			
1997	434	23.4	759
1998	443	25.6	789
1999	347	25.2	761
Mean[c]	500	24.0	732
Whole year			
1997	1073	17.8	1267
1998	1111	19.3	1303
1999	1041	18.7	1301
Mean[c]	1092	17.8	1215

[a] Growing season from April to August.

[b] Potential evapotranspiration calculated according to the standardized reference method of the American Society of Civil Engineers (Walter et al., 2000).

[c] Long term means from 1986 to 2000.

crop) or discing twice before sowing corn. The four deep tillage treatments were varied from year to year to maintain deep tillage at least once in every 3 years (Table 3), because after 3 years effects of residual deep tillage are usually not noticeable (Busscher et al., 1995). Treatments were replicated four times in a randomized complete block design.

Surface tillage, deep tillage, and sowing were done in separate operations. All tillage and harvesting equipment followed the same wheel tracks as closely as possible. Surface tillage was done with a 3 m-wide Tufline disc (Tufline, Columbus, GA) pulled by a John Deere 4230 (Deere, Moline, IL) 75 kW tractor with wheels on 1.6 m centers. (Mention of trade names or commercial products in this paper is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture or Clemson University.) Surface tillage disrupted approximately the top 0.15 m. Deep tillage was done with a four-shank Paratill (Tye, Lockney, TX). Shanks were set 0.66 m apart. The Paratill was pulled with a Case 2670 (now Case-IH, Racine, WI) 165 kW, 4-wheel-drive tractor with dual front and rear wheels on 1.9 and 3.1 m centers. Paratill shanks deep-tilled the soil to 0.4 m (approximately the bottom of the E horizon).

Following Clemson soil test recommendations (Clemson University, 2000), N, P, and K were preplant broadcast on all plots. Rates were 35 kg ha^{-1} P as P_2O_5 and 70 kg ha^{-1} K as K_2O in 1997, 25 kg ha^{-1} P as P_2O_5 and 46 kg ha^{-1} K as K_2O in 1998 and 1999. Two hundred kilograms per hectare N as NH_4NO_3 were also broadcast every year. Fertilizers were applied with a 3 m-wide Gandy spreader (Gandy, Owatonna, MN) pulled by a Massey Ferguson 253 tractor with

Table 3
Dates of planting and tillage for the four deep tillage treatments

Dates of planting	Dates of last deep tillage for the four deep tillage treatments			
1 April 1997	Not tilled[a]	31 March 1997	5 June 1996	19 November 1995
31 March 1998	Not tilled	30 March 1998	5 June 1996	19 November 1995
5 April 1999	Not tilled	30 March 1998	5 June 1996	4 April 1999

[a] At the beginning of the 1999 corn growing season, the not-tilled treatment had not been tilled for over 5 years.

wheels on 1.9 m centers. Lime (2240 kg ha^{-1}) was spread in 1999 by a commercial lime truck spreader.

2.3. Cropping

Plots were sown to corn (DeKalb 687). Corn was sown on 0.38 m row widths with a John Deere 750 drill in 1997 and with an 8-row Monosem planter (A.T.I., Lenexa, KS) in 1998 and 1999 pulled by a Massey Ferguson 398 (Massey Ferguson, Des Moines, IA) 60 kW tractor with wheels on 1.9 m centers. Corn was sown on 1 April 1997, 31 March 1998 and 5 April 1999 at a rate of 3 seeds m^{-1} and harvested on 28 August 1997, 18 August 1998, and 24 August 1999.

To determine the yield, grain was hand harvested from 12 m of the middle four rows in each plot and threshed using a plot combine located outside the experimental area. Yield data were corrected to 0.155 kg kg^{-1} moisture. Grain for the rest of the plot was harvested with a Case-IH (Case-IH, Racine, WI) 2366 combine with a 4.6 m wide-corn header and wheels on 3 m centers. Since the corn header was designed for 0.76 m-row widths, two 0.38 m-row widths were harvested with each header opening.

To control weeds, plots were sprayed with alachlor plus glyphosate (2-chloro-2′,6′-diethyl-*N*-(methoxymethyl)acetanilide plus *N*-(phosphonomethyl)glycine) at a rate of 3.9 kg a.i. ha^{-1} before sowing corn. When plants were 0.25 m tall, plots were sprayed with 2 kg a.i. ha^{-1} atrazine (6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine).

2.4. Cone index measurements

Cone index data were taken with a 12.5 mm diameter cone-tipped penetrometer (Carter, 1967) on 22 April 1997, 29 April 1998, and 13 April 1999. Cone indices were measured by pushing the penetrometer into the soil to a depth of 0.55 m at nine positions spaced 95 mm apart starting at the middle of the plot and moving outward to one side of the plot into a wheel track. Cone index data were digitized into the computer at 50 mm depth intervals and log transformed before analysis according to the recommendation of Cassel and Nelson (1979). Data for all positions across the plot and depth were combined to produce cross-sectional contours of soil cone indices using the method of Busscher et al. (1986).

Gravimetric soil water content samples were taken along with cone indices. They were taken at the first and fifth positions of cone index readings. Water contents were measured with two combined 250 mm diameter samples taken at 0.1 m depth intervals to the 0.6 m depth. These water contents were taken as representative of the plot. Rainfall data were collected at a weather station located approximately 700 m from the field plots.

2.5. Statistical analysis

Cone index and water content data were analyzed with the ANOVA and the least square mean separation procedures (SAS, 1990). Data were analyzed using a split–split plot randomized complete block design where the first split was positioned across the row and the second split was depth. Since treatments varied from year to year (since previous deep tillage was another year older with each ensuing year), data were analyzed separately for each year.

Corn grain yield was analyzed as a function of mean profile cone index using the linear regression procedure, REG (SAS, 1990). Mean profile cone indices were averages of cone index data for all readings for the nine positions in 0.76 m across the rows and the 50 mm depth intervals 0.55 m into the soil. Slopes of regression lines for each year were tested for difference using the general linear modeling procedure, GLM (Johnson et al., 1994, p. 119). For multi-year regressions, rainfall amounts were grouped by intervals of 1-, 2-, and 4-week periods after sowing corn. Appropriate intervals were added to the regression of yield and cone index using the stepwise procedure (SAS, 1990). After the data for corn were regressed, data from the previous experiment with soybean (Frederick et al., 1998) were regressed using the same procedure. Data were tested for significance at the 5% level, unless otherwise specified.

3. Results and discussion

3.1. Water content

Soil water contents were not significantly different between surface tillage treatments, among deep tillage treatments, or among any interactions. Water contents varied with depth (Table 4), generally increasing with

Table 4
Soil water contents as a function of depth averaged over surface and deep tillage treatments for each year of measurement of cone indices

Depth (mm)	Water content[a] (kg kg^{-1})		
	22 April 1997	29 April 1998	13 April 1999
50	0.10 d[b]	0.10 d	0.07 d
150	0.09 d	0.10 d	0.07 d
250	0.10 c	0.11 d	0.09 c
350	0.12 b	0.12 c	0.11 b
450	0.13 a	0.15 b	0.13 a
550	0.14 a	0.16 a	0.13 a
Mean	0.11	0.12	0.10

[a] Soil water contents were not significantly different among treatments or treatment interactions with depth.

[b] Means within the columns with the same letter are not significantly different by the LSD test at $P = 0.05$.

Table 5
Mean profile cone indices for deep tillage treatments averaged over disced and non-disced treatments

Time of last deep tillage[a]	Cone index (MPa)		
	22 April 1997	29 April 1998	13 April 1999
Not deep tilled	2.56 a[b]	2.86 a	3.30 a
12 December 1995	1.81 b	2.08 b	–
13 June 1996	1.61 b	2.06 b	2.92 b
31 March 1997	1.23 c	–	–
30 March 1998	–	1.25 c	2.35 c
4 April 1999	–	–	1.64 d

[a] Except for the non-deep tilled plots, treatments were not allowed to go more than 3 years without deep tillage.

[b] Means within columns with the same letter are not significantly different by the LSD test at $P = 0.05$.

depth. Because of the lack of treatment effects, water contents were ignored for the analysis of cone indices, except when considering depth. The lack of variability in water content can be seen by low mean square errors: 0.0013 kg kg^{-1} for 1997, 0.0017 kg kg^{-1} for 1998, and 0.0015 kg kg^{-1} for 1999.

3.2. Cone index

Cone index readings were significantly different for deep tillage treatments and their interactions with position and depth. In all cases, cone indices were highest for treatments that were not deep tilled and lowest for treatments that were more recently deep tilled (Table 5 and Figs. 1 and 2).

Cone index differences for the deep tillage by position interaction were the result of paratilled vs. non-paratilled treatments. Cone indices at the mid-position readings (position = 0.38 m in Figs. 1 and 2) were lower than the other positions for treatments that had been paratilled. Cone index differences were significant for fewer positions of measurement (near position = 0.38 m) as the time between paratilling and measurement increased, as the effect of paratilling

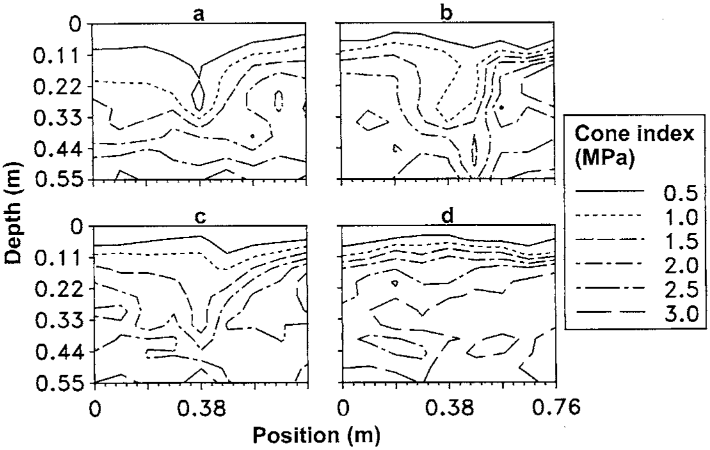

Fig. 1. Cone index contours for the spring 1997 disced treatments. The time of deep tillage was (a) spring 1997, (b) spring 1996, (c) fall 1995, and (d) not deep tilled. Readings were taken from non-wheel track position under the center of the tractor to a wheel track.

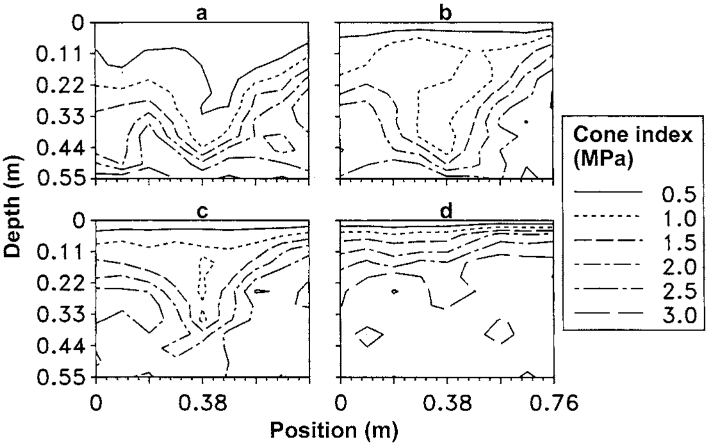

Fig. 2. Cone index contours for the spring 1997 non-disced treatments. The time of deep tillage was (a) spring 1997, (b) spring 1996, (c) fall 1995, and (d) not deep tilled. Readings were taken from non-wheel track position under the center of the tractor to a wheel track.

diminished over time. The treatment that was not paratilled showed no mid-position vs. other position differences.

Another cone index difference of deep tillage by position was caused by wheel traffic. Cone indices were lower for the non-wheel traffic position (position = 0 m of Figs. 1 and 2) when compared with wheel traffic position (position = 0.76 m) for all seven instances where treatments had been subsoiled within the past 2 years or less, as also reported by Reeves et al. (1990) and Wiermann et al. (1999). By contrast, cone indices were lower for non-wheel traffic position vs. wheel traffic position in only one (the non-tilled treatment in 1999) of five instances where treatments had not been subsoiled or had been subsoiled 2.5 or 3 years before measurement. This finding was in slight contrast to earlier findings that subsoiled treatments equalled non-subsoiled treatments 3 years after tillage (Busscher et al., 1995), indicating perhaps slightly faster recompaction in this experiment.

Cone index differences for the tillage with depth interaction were a result of discing that loosened the soil near the surface (Fig. 1). Despite the looser soil near the surface of the disced treatments, mean profile cone indices were significantly higher for the non-disced treatments only in 1999. For the non-disced vs. disced treatments, cone indices were 1.77 vs. 1.72 MPa in 1997, 1.91 vs. 2.05 MPa in 1998, and 2.31 (1.38) vs. 2.64 (1.44) MPa in 1999 (LSD at 5% = 0.04). Numbers in parentheses are log transforms. Log transforms are presented because analyses and LSDs are based on them. To prevent taking log(0) in the transforms, 0.1 was added to each reading before transformation and subtracted after.

For deep tilled treatments, discing did not necessarily reduce overall soil strength. When deep tillage treatments were analyzed separately, cone indices in the top 50 mm, the upper third of the disced zone, were not consistently lower for disced or non-disced treatments. For disced treatments that had been deep tilled during the past 2 years, cone indices were higher for the 0.1–0.3 m depth than for the non-disced treatments. Higher cone indices for the disced treatment suggests that discing increased soil cone index below the disced zone. No consistent trend was seen for treatments not deep tilled for 2 years or more, probably because temporal factors of settling and loosening, such as wetting and drying or multiple discings, eliminated the differences.

3.3. Regressions of cone index and yield

Treatments provided a wide range of mean profile soil cone indices (0.9–6 MPa, means of cone index data points for all depths, 0–0.55 m, and all positions, 0–0.76 m across a row for each treatment, e.g. Figs. 1 and 2) averaged over replicates; and they provided a wide range of corn grain yields (3.76–10.4 Mg ha^{-1}) averaged over replicates to use for regression analyses.

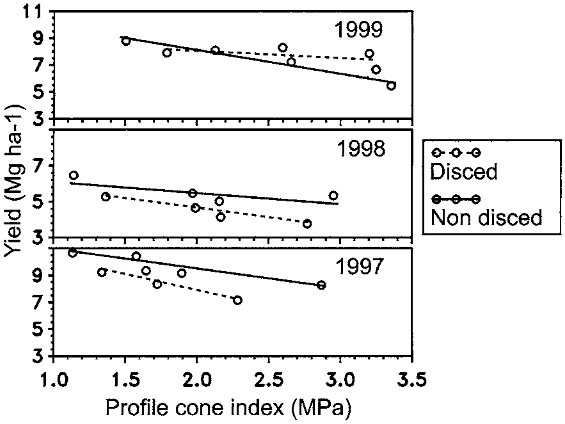

Fig. 3. Corn yield decrease with increase of cone index analyzed for disced and non-disced treatments for each year. Data points are means of four replications. Coefficients of determination (r^2) are 0.84 ($P < 0.08$) and 0.91 ($P < 0.05$) for disced and non-disced treatment in 1997, 0.74 ($P < 0.14$) and 0.34 ($P < 0.41$) for disced and non-disced treatment in 1998, 0.27 ($P < 0.48$) and 0.96 ($P < 0.02$) for disced and non-disced treatment in 1999.

Regressions showed that corn grain yields decreased with increasing mean profile cone index, as previously for soybean and wheat (Busscher et al., 2000). For each year, corn grain yield as a function of mean profile cone index was significant or marginally significant ($P = 0.05$ with $r^2 = 0.57$ in 1997, $P = 0.11$ with $r^2 = 0.37$ in 1998, $P = 0.05$ with $r^2 = 0.51$ in 1999). When yield was expressed as a function of mean profile cone index separately for disced and non-disced treatments, in four of the six cases (Fig. 3), regression coefficients were higher than for yearly values. Based on the slopes of these six linear regressions (Fig. 3), yields were reduced between 0.5 and 2.4 Mg/ha for each MPa increase in mean soil profile cone index. Neither the disced nor the non-disced management system provided a better prediction of yield with cone index and neither had consistently higher reductions in yield with increased mean profile cone index.

The slopes of the six curves in Fig. 3 were not significantly different; models of equal slopes adequately described the data. Equal slopes implied a similar corn grain yield response to changing mean profile cone index over years. However, when data for all years were combined, data were too scattered to provide a significant relationship. The most likely cause of scatter from year to year would be water content of the soil and/or rainfall. For further analysis, we included rainfall.

Amounts of rainfall that had been grouped by intervals of 1-, 2-, and 4-week periods after sowing (Fig. 4) were selected and added to the regression using the stepwise procedure (SAS, 1990). Stepwise picked the variables cone index, rainfall at 7–8 weeks after sowing ($R^2 = 0.80$), and finally, rainfall at 11–14 weeks after sowing ($R^2 = 0.87$, Fig. 5) as having the most effect on corn yield. Stepwise did not pick

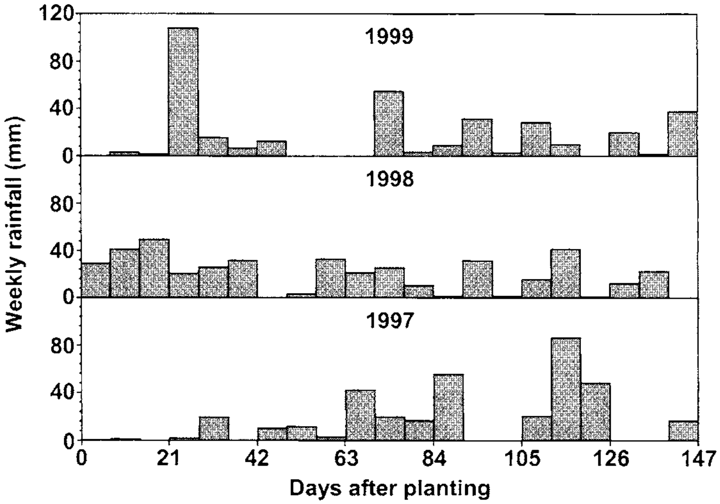

Fig. 4. Weekly total rainfall amounts for the corn growing seasons of the years shown.

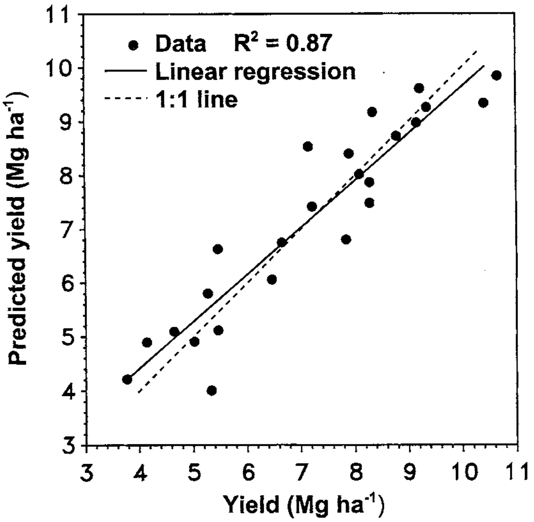

Fig. 5. Comparison of corn yield with yield predicted by $y = 2.36 - 1.13\,\mathrm{mc} + 0.114\,\mathrm{tw} + 0.068\,\mathrm{fw}$, where y is the predicted yield, mc the mean profile cone index, tw the rainfall in the 2-week period 42–56 days after sowing (DAS), and fw the rainfall for the 4-week period 70–98 DAS.

rainfall periods with particularly high or low values. Weeks 7–8 (42–56 days after sowing (DAS)) fell within the vegetative growth stage; weeks 11–14 (70–98 DAS) fell within silking which was 91 DAS in 1997, 81 DAS in 1998, and 79 DAS in 1999. Silking has been documented as a growth stage when corn is most sensitive to drought (Ritchie et al., 1986), especially for sandy coastal plain soils. The selection of these growth stages does not mean that other growth stages are less important or need less water; but for these years, rainfall at silking and early vegetative growth along with mean profile cone index was able to explain yield variability for the 3 years in one relationship rather than three (Fig. 5).

Soybean yield data from the previous experiment on the same plots (Frederick et al., 1998) were used to verify the regressions procedure. Regressions of yield as a function of mean profile cone indices for each year were 0.67 for 1994, 0.68 for 1995, and 0.84 for 1996, with regression lines that were somewhat parallel (Busscher et al., 2000). When all 3 years were considered together with yield as a function of only cone index, the regression was 0.46. Grouping rainfall amounts in intervals of 1 (Fig. 6), 2, and 4 weeks, again using stepwise, improved the regression to 0.73 (Fig. 7). Rainfall intervals added by the stepwise procedure were the 4-week period 70–98 DAS and total rainfall for the growing season. The 4-week period covers initial flowering at 80 DAS in 1994, 82 DAS in 1995, and 70 DAS in 1996 through full pod stage (seed fill stage was 99 DAS in 1994, 99 DAS in 1995, and 87 DAS in 1996 (Frederick et al., 1998)). Early reproductive development was a time of importance for rainfall when flower appearance and flower retention were determined. The addition of total rainfall

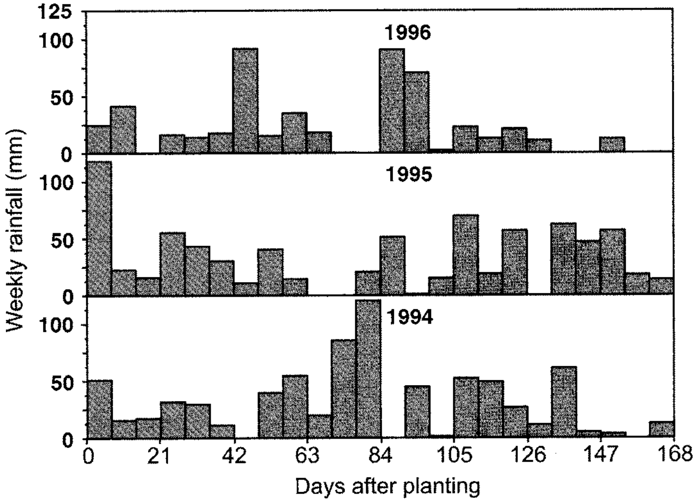

Fig. 6. Weekly total rainfall amounts for the soybean growing seasons of the years shown.

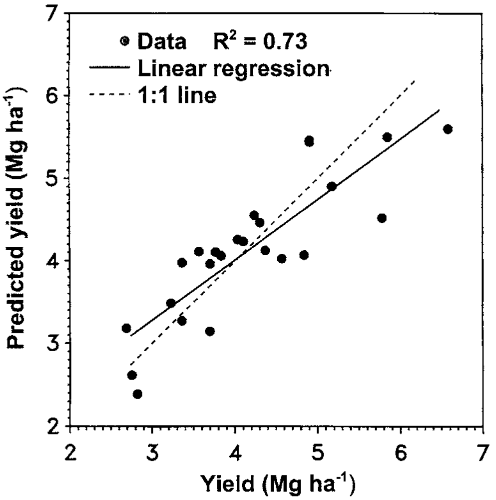

Fig. 7. Comparison of soybean yield with yield predicted by $y = 2.20 - 1.39\,\mathrm{mc} + 0.0029\ \mathrm{tot} + 0.011\,\mathrm{fw}$, where y is the predicted yield, mc the mean profile cone index, tot the rainfall for the total growing season, and fw the rainfall for the 4-week period 70–98 DAS.

(740 mm in 1994, 810 mm in 1995, and 591 mm in 1996) to the regression may reflect the soybean plant's ability to compensate at one stage for yield reducing stress at an earlier stage (Frederick and Hesketh, 1993; Board and Harville, 1998). Larger data sets with more years of data would be helpful for further validation.

4. Conclusions

For this narrow-row management system, the effectiveness of deep tillage decreased with time; soil strength increased and yield decreased as time elapsed between deep tillage and measurement. Relationships for each year that related the decrease in yield to the increase in soil strength ranged in regression coefficient from 0.37 to 0.57 (0.27–0.96 if analyzed separately for disced and non-disced treatments). When analyzed for all 3 years together, the relationship was meaningless unless rainfall for selected times of the year (vegetative growth and silking) were included. The regression relationship for all years together then improved to 0.87.

To verify the procedure, soybean grown in the same plots for the three previous years were analyzed in a similar manner; similar results were obtained with a regression coefficient of 0.73. For the soil of this study, yield variations from plot to plot were successfully described by a combination of mean profile soil cone index and rainfall from selected times during the growing season.

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