Effect of strength and organic matter buildup on yield in long-term conservation vs. conventional tillage plots

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Abstract
Long-term tillage plots were established in 1978 to determine organic matter buildup in coastal plain soils for row crop production. Plots were cropped to a two-year rotation of maize, wheat, and soybean with both phases of the rotation grown each year in duplicate sets of plots. Every year, plots were either surface tilled to 0.15 m and deep tilled to 0.4 m to break up a genetic hard layer or deep tilled only. In 1996, plots were split; half of the plots were deep tilled and half not deep tilled to examine buildup of soil strength over time, its effect on yield, and how organic matter buildup over time in conservation tillage plots could compensate for strength buildup. After 2001, no plots were tilled permitting observation of treatments that had not been tilled for differing periods of time. Organic matter buildup in conservation tillage plots improved yield if plots were not deep tilled; but yield increase was not as effective as it was for deep tillage. In 2004, conventional tillage plots in which tillage ceased in 2001 had reconsolidated to the point that their soil strength was not different from conventional tillage plots in which tillage had ceased in 1996. However, the same comparison for conservation tillage showed lower soil strengths in the plots where tillage ceased in 2001, suggesting that conservation tillage can help buffer the effects of reconsolidation.

Keywords: soil strength, compaction, cone index, conservation tillage, hardpan

1. Introduction

High soil strengths can limit plant growth in many soils, especially the Coastal Plain soils of the southeastern USA where the E horizon can have strengths that reduces yield of row crops like maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean (*Glycine max* L. Merr.) (Arvidsson et al., 2001). High strengths can be reduced and yield improved through deep tillage which is recommended annually (Porter and Khalilian, 1995) or seasonally for double crop systems (Frederick et al., 1998).

Subsoilers are typically used to till these sandy coastal soils; they provide a non-inversion deep tillage that breaks up subsurface hard layers. Deep tillage loosens the soil to allow root growth through the hard layer into deeper horizons that have a higher degree of structural development and greater water holding capacities; deep tillage can encourage root growth and improve yield (Akinci et al., 2004). Deep tillage may become prohibitively expensive because it requires 14 to 20 kw per subsoil shank, uses 20 to 25 liters of fuel ha^{-1}, and its effect is temporary (Carter et al., 1996; Busscher et al., 2000). Another way to enhance soil for improved growth has been to increase soil organic matter. Research has shown that OM increased in conservation tillage systems, though the increase was only in the top few centimeters. Increased organic matter has the potential to improve growth with less tillage (Hunt et al., 2004).

We measured differences between deep-tilled and non-deep-tilled treatments after deep tillage ceased in conventional (disked) and conservation (non-disked) tillage plots. We hypothesized that plots where deep tillage ceased would re-compact to values equivalent to non-deep-tilled plots within three years. We tested the hypothesis by measuring differences in

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soil strength between treatments as they changed over the years, regardless whether organic matter had build up in the surface from conservation tillage or not.

2. Materials and methods

The study was conducted on a long-term research site that had conventional (disked) and conservation (non-disked) tillage plots established in 1978 on a Norfolk loamy sand (an acrisol or a fine-loamy, siliceous, thermic *Typic Kandiudult*) near Florence, South Carolina. The Norfolk soil formed in coastal marine sediments. It has an Ap horizon that had been tilled over the years to a depth of about 0.20 m. Below the tilled layer, it had an eluviated E horizon that typically varied in depth from 0.30 to 1.0 m and when re-compacted developed penetration resistance that restricts root growth. The E overlaid a sandy clay loam Bt horizon at about the 0.6-m depth.

Between 1978 and 1997, crops grown on the plots included maize and winter wheat double cropped with soybean or cotton (Hunt et al., 2004). During that time, organic matter increased to about 14 g kg^{-1} in the top 100 mm of the profile of the conservation tillage plots while it rose to 8 g kg^{-1} at the same depth interval for the conventional tillage plots.

In this study, maize and wheat with double-cropped soybean were grown in a two-year rotation; both phases of the rotation were planted in duplicate sets of plots. The study was initiated in November of 1997 when wheat was planted in half of the plots. The following spring maize was planted in the other plots; and, after wheat harvest, soybean was planted in the wheat plots. Main plot treatments included surface tillage (conventional vs. conservation tillage). Conventional tillage consisted of multiple diskings of the surface 0.10 to 0.15 m; conservation tillage consisted of no surface tillage. Subplot treatments included no deep tillage vs. non-inversion deep tillage of the E horizon with the ParaTill (AGCO, Duluth, GA)[1]. The ParaTill had four 25-mm-wide subsoiling-legs that were 0.66 m apart; each leg was preceded by a serrated coulter. Legs were 0.94-m long with a 45^o bend (left legs bent to the right row and right legs bent to the left) 0.69 m from the top. Each leg had a 64-mm wide point which was set to a soil depth of 0.42 m. Each leg had a shatter plate above and behind the point to provide lifting and fracturing of soil with minimal disturbance of the soil surface. Appropriate plots were paratilled immediately prior to the planting of maize, wheat, and soybeans, resulting in three subsoiling events in a two-year rotation.

Every year, conventional tillage plots continued to be surface tilled. Until fall of 1995, all plots were deep tilled. Starting in spring 1996, surface-tillage plots were split into two 60-m-long and 11.4-m-wide deep-tillage subplots that were either deep tilled or not. After 2001, no plots were deep tilled while surface tillage continued. Plots did not have controlled traffic. The experimental design was a split plot with four replications.

Soil strength was measured as cone index of a penetrometer in soybean plots on 29 July to 3 August, 1998; 11 May 1999; 31 July, 2000; 2 August, 2001, 28 June 2002, 25, 27 June 2003, and 30 June 2004. Dates of measurement varied because many of these years were dry and rain was often required to soften the soil and allow measurements to be within the range of the penetrometer. Soil cone index data were taken with a 12.5 mm diameter, 30^o solid angle cone tip attached to a hand-operated, recording penetrometer. Cone indices were measured near the middle of each tillage subplot to a depth of 0.55 m at nine equally spaced positions along a 0.76 m-transect across the rows. Until 2002, cone indices were recorded on index cards as analog data and digitized at 50 mm depth intervals. After 2002, cone indices

[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of a product to the exclusion of others that may be suitable.

were measured with a strain gauge; depth was measured with a potentiometer; and data were downloaded to a CR21x or CR23x (Campbell Scientific, Inc., Logan, Utah). Automated data were collected at a rate of 100 hz. Data were analyzed using the log transform of the cone index. Soil samples were taken along with cone indices to measure gravimetric water contents. Soil samples were taken at 0.1-m intervals to 0.6-m depths.

Growing-season weeds in conventional tillage plots of maize were controlled by disking and chemicals; weeds in conservation till plots were controlled only with chemicals. Fertilizer was applied at the rate of 15, 10, and 90 kg ha^{-1}, for N, P, and K. Maize (cv. Pioneer 34SA55 Liberty Linked) was planted in late March or early April at a rate of 59,300 seed ha^{-1} on 0.76-m-row spacing. Liquid N was surface applied in May of each year at the rate of 110 kg N ha^{-1}. Maize was harvested in August or September with a Case IH Model 2366 combine.

In October, plots were either disked or sprayed with Glyphosate for weed contol. In November, plots received fertilizer 50, 14, 15, and 1120 kg ha^{-1} of N, P, K, and lime. Also in November, wheat (cv. Coker 9835) was planted with a no-till grain drill (John Deere Model 750) at a seeding rate of 100 kg seed ha^{-1} on 0.19-m row spacings. Ammonium nitrate was broadcast in February and wheat was harvested in June with a Case IH Model 2366 combine.

Following wheat harvest, plots were either disked or sprayed with Glyphosate for weed control and fertilized (10 kg P ha^{-1} and 56 kg K ha^{-1}) before planting. Soybean (cv. Northrup King 573Z6) was planted in June at a rate of 112 kg ha^{-1} with the no-till grain drill. In October or November, soybean was harvested with a Case IH Model 2366 combine.

Soil organic carbon (SOC) was measured in soil core samples (to 90-cm deep) that were collected annually in the plots after corn harvest. SOC contents were measured by dry combustion and were expressed as g kg^{-1} on cores taken at depths of 0-5, 5-10, 10-15, 15-30, 30-45, 45-60, and 60 to 90 cm.

Soil strength and water content data were analyzed using ANOVA and a least square mean separation procedure. Because the data were collected over a 7-y time period and because conditions differed from year to year, data were analyzed by year. Cone index and water content data were analyzed using a split plot randomized complete block design where the first split was deep tillage, the second position across the row, and the third depth. SOC data were analyzed by calculating the mean SOC contents on a weight basis by pooling values across tillage treatments and years (1994 to 2003). Mean profile SOC contents were compared between tillage treatments using a Students t-test. Data were tested for significance at the 5% level unless otherwise stated.

3. Results and discussion

In conservation tillage systems, organic matter has been reported to increase near the surface by not mechanically mixing crop residues into the plow layer (Hunt et al., 2004). In this study, organic matter was enriched near the surface (Fig. 1. 0 to 5-cm deep) where it differed significantly ($P < 0.05$) from organic matter contents in treatments where the soil was disked. Below 5-cm, organic matter contents were similar between tillage treatments (Fig. 1).

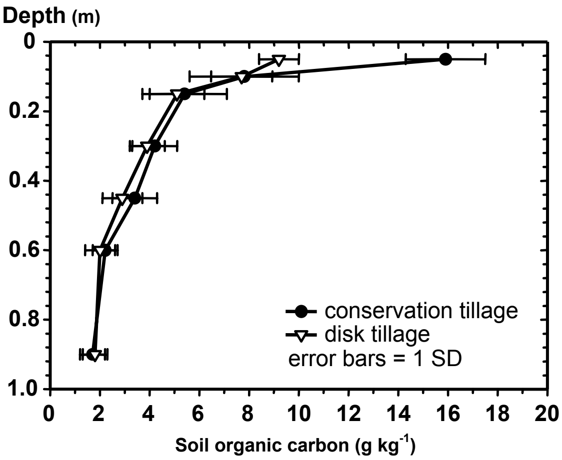

Figure 1. Soil organic carbon buildup in soils that were disked to mix organic matter into the soil or not (leaving it on the surface).

Soil water content differences affect cone index readings. To avoid this, we measured cone indices after a rainfall when water contents were uniform. Soil water content differences (data not shown) were not significantly different for treatments though they generally increased with depth. Because of similarity among treatments, soil water contents were not included in analyses, except where listed.

Cone index data from 1998 were analyzed for disked and non-disked tillage treatments separately. They did not differ by deep tillage treatment, despite the fact that deep tillage had ceased for one of the split treatments two years earlier (Fig. 2). In later years, cone indices for non-deep-tilled treatments had significantly higher values than for those that continued to be deep tilled; this was especially evident in 1999 and 2001.

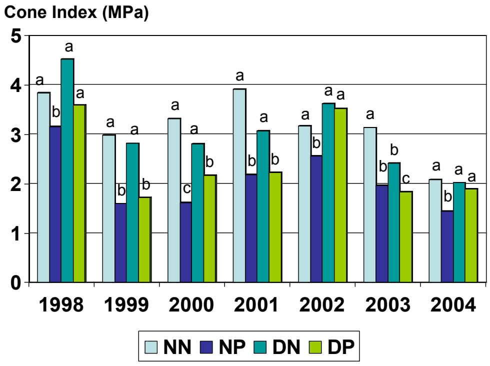

Figure 2. Mean cone indices of the profile for no surface or deep tillage since 1996 (NN), no surface and no deep tillage since 2001 (NP), disked with no deep tillage since 1996 (DN), and disked with no deep tillage since 2001 (DP).

Deep tillage ceased on all plots in 2001. As the years passed, cone index differences decreased between plots where deep tillage ceased in 1996 and those where it ceased in 2001 (Fig. 2). Cone indices differences for disked plots appeared to be decreasing faster than those that were not disked suggesting that disking was increasing soil reconsolidation. Increased organic matter in the non-disked treatments could be slowing reconsolidation of the hard soil. But, that would be only near the surface.

Although plots had not been tilled for three or eight years, cone index plots showed that positions of deep tillage could still be detected by lower strengths under the rows (Fig. 3). Evidence of deep tillage was more obvious in treatments that were deep tilled more recently (NP and DP in Fig. 3) or had not been disked (NN and NP). The fact that reduced cone indices continued to be detected even when differences were not significant supports the work of Baumhardt and Jones (2002) and Busscher et al. (2000).

Soil water contents appear high because readings were taken after rain. Most years were droughty; rainfall deficits were 180 mm or more when compared with the 120 year mean of 1139 mm and because of poor rainfall distribution during the growing seasons, see for example the flat sections of the cumulative rainfall in 2001 (Fig. 4).

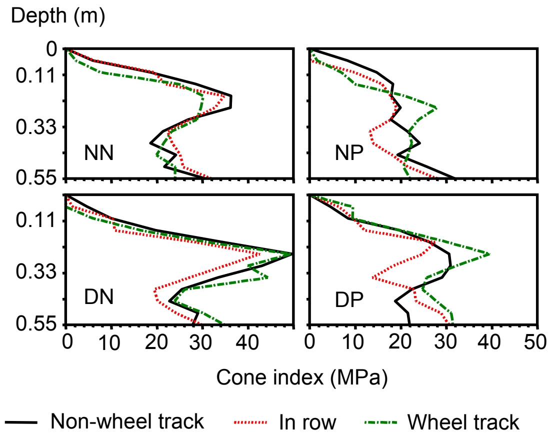

Figure 3. Cone indices in 2004 of soil profiles for treatments with no surface or deep tillage since 1996 (NN), no surface tillage or deep tillage since 2001 (NP), surface tillage and no deep tillage since 1996 (DN), and surface tillage and no deep tillage since 2001 (DP).

Rainfall deficits were severe enough to cause mean cone indices at the times of measurement to exceed 2 MPa every year except 2004; 2-MPa cone indices were considered root limiting. High cone indices (Fig. 2) were likely related both to rainfall deficits (especially in 2001 and 2002) and the high-strength nature of the soil profile (Busscher et al., 2000).

For information on cone indices and yield in this experiment, see Hunt et al. (2004). They concluded that the increased organic matter accumulation in the surface layer of the non-disked treatments partially compensated for the need to deep till and yet deep tillage was beneficial for maize and wheat yields.

4. Conclusions

In 1999, split-plot treatments where tillage ceased three years earlier had significantly higher cone indices than treatments that were still being deep tilled. Additionally, plots that were not being tilled had no differences in cone indices for the positions across the rows.

In 2004, three years after deep tillage ceased on all plots, conventionally tilled plots did not have significantly lower cone indices than plots that had not been tilled for eight years. Plots with conservation tillage still showed reduced cone indices for the plots not tilled since 2001. Additionally, no plots had differences in cone indices for the positions across the rows.

During most years, cone indices were above 2 MPa which was considered to be a root limiting value. This was attributed to both soil re-compaction and rainfall deficits.

At the end of the experiment, treatment effects could still be observed in plots of cone index readings despite the fact that the data may not have been significantly different.

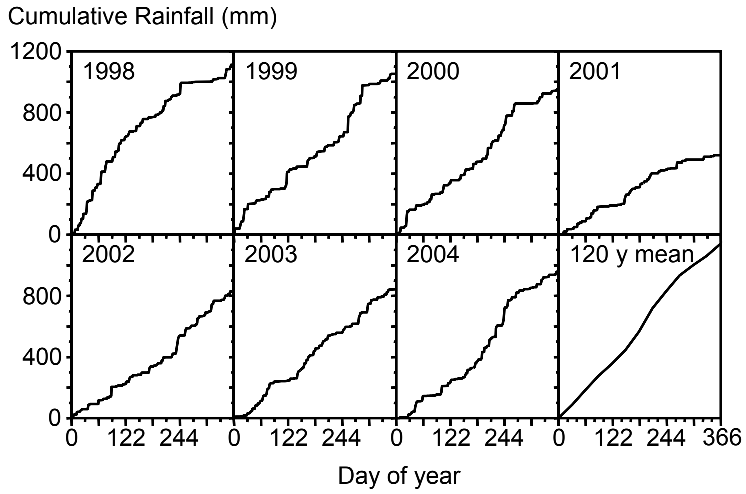

Figure 4. Cumulative rainfall over the course of the experiment. The Mean is the average for 120 years 1882 to 2001.

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