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Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt

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A R T I C L E I N F O

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A B S T R A C T

Scientists have dedicated many decades and resources to studying the effects of tillage on soil properties and crop yields. However, the literature lacks empirical data on corn/soybean yields and their stability to variable-weather years under long-term management at multiple locations in mid-Western USA. Thus, the objective of the current study was to evaluate yields and their stability from 2009 through 2013 at eight long-term sites with no-till (NT) and chisel-plow (CP) managed continuous corn (CC) and corn (*Zea mays*)-soybean (*Glycine max*) rotations (C-s and c-S for corn and soybean phase). The tillage-treatment durations among the eight sites ranged from eight to 51 years in the Midwestern U.S. Corn Belt. The data indicates that tillage had no significant effect on long-term crop yields, with a few exceptions. During one site-year (southern Minnesota in 2012) in the CC system, NT yielded significantly 15.2% more than CP (9.1 vs. 7.9 Mg ha^{-1}). However, CC yields averaged across sites were significantly 10.5 and 13.6% more in CP than NT in 2009 and 2010, respectively (12.6 vs. 11.4 Mg ha^{-1} in 2009; 12.5 vs. 11.0 Mg ha^{-1} in 2010). In the corn-soybean rotations, CP yielded significantly 18.7% more than NT (12.7 vs. 10.7 Mg ha^{-1}) when averaged across years at one site in Iowa for the C-s phase. Yield stability indexes to environmental conditions indicated no differences in NT than CP yield stabilities among variable-weather years. However, NT had significantly lower range of relative yields across the variable-weather years as compared to CP for the CC system and C-s phase. These direct and synthesized data provide evidence of little to no differences between CP and NT managed corn/soybean research plots exist in the Midwestern US. Although CP may produce greater yields when averaged across the region's research plots during some years, this effect was not evident at the individual research plot scale.

1. Introduction

Agronomists and soil scientists have dedicated many decades and resources in studying the effects of tillage practices on soil properties and crop yields (Call and Sewell, 1918; Sewell, 1919; Wilhelm and Wortmann, 2004; Triplett and Dick, 2008; Pittelkow et al., 2015a,b; Daigh and DeJong-Hughes, 2017). A search for the terms "tillage" or "no-till" (NT) in article titles from the Web of Science Core Collection results in over 9900 publications from 1900 to 2016 (data accessed on Dec. 5th, 2016). A majority of these publications contains data on fields at one or two locations and in years immediately following a change in tillage management (i.e., field conditions in a state of nonequilibrium with the new management practice) (Pittelkow et al., 2015a,b). This issue is not surprising for any area of agricultural research given the difficulties for sustaining long-term funding resources, access to land, evolving research priorities, and advances in the science. As a result, the scientific literature rarely receives empirical data on corn (*Zea mays*)/soybean (*Glycine max*) yields and their yield stability among

Abbreviations: NT, no-till; CP, chisel plow

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variable-weather years under long-term tillage and simultaneously at multiple locations. For the purposes of this paper, "long-term" refers to fields managed for eight to 50 years or more with the same tillage practices (Linden et al., 2000).

Of the few long-term tillage studies available in the literature, mixed results are reported of chisel plowing (CP) vs. NT effects on crop yields. During a 30-year study in Iowa, Karlen et al. (2013) reported that CP yielded similarly or significantly more than NT for continuous corn (CC) or rotated corn-soybean fields (C-s and c-S for corn and soybean phases). However, when CP yielded more than NT, the yield differences tended to be small (i.e., typically < 1.0 Mg ha^{-1}) and occurred most often in the CC and C-s fields. Griffith et al. (1988) observed lower plant populations (i.e., differences of 1393–2722 plants ha^{-1}) in NT vs. CP for both CC and C-s fields during a 12-year study in central Indiana. The CP yielded significantly higher than NT during four years in CC and two years in C-s during the 12-year study. In contrast, they observed similar or significantly higher plant populations (i.e., up to 2469 plants ha^{-1}) in NT vs. CP fields during 7 years at a second research site in southeastern Indiana. However, the CP also yielded significantly higher than NT at the southeastern Indiana site during three years in CC and two years in C-s despite NT producing higher plant populations. In contrast to these long-term studies, Sindelar et al. (2015) reported that NT fields yielded similarly or significantly more than other tillage practices (e.g., moldboard plow, CP, and tandem disk) in a 28-year study from 1986 to 2013 near Lincoln, Nebraska. These observations occurred after 13 years for CC and C-s and 11 years for c-S from when the tillage treatments were first implemented (Sindelar et al., 2015). In a 31-year study from 1982 to 2012 in Ontario, Gaudin et al. (2015) reported that crop yields were 7 and 22% higher in corn and soybean fields during dry years when tillage was reduced and corn-soybean cropping sequences become more diverse with small grains. Gaudin et al. (2015) reported that more diverse crop rotations not only reduces the potential for crop failure in adverse weather years, but reduces yield time lags for reduced tillage systems (e.g., CP and NT) as compared to moldboard plowing (Gaudin et al., 2015). Al-Kaisi et al. (2015) also reported that tillage-induced differences among long-term corn and soybean yields were dependent on crop rotation at seven sites in Iowa from 2003 to 2013. However, in contrast to Gaudin et al. (2015), they report that NT in corn-soybean rotations had a significant negative effect on crop yields and economic returns as compared to CP. Whereas, no differences in yields and economic returns were observed among NT and CP in the monocropped CC systems at all seven sites in Iowa (Al-Kaisi et al., 2015).

Short-term tillage reports at one or two locations do offer substantial inferences to long-term crop yield trends. For instance, both short-term and long-term tilled fields are vulnerable to soil crusting, which lowers crop yields due to the crust's physical effects lowering plant emergence as well as the potential to infiltrate and store water during subsequent rainfall events (Cassel et al., 1995). High levels of residue cover on poorly drained soils are reported to have delayed plant emergence and maturity with subsequent yield losses under both short- and long-term field studies (Griffith et al., 1973; Mock and Erbach, 1977; Dick and Van Doren, 1985; Al-Darby and Lowery, 1986). However, Griffith et al. (1988) reported that these effects were limited to poorly drained soils with high organic matter (OM) contents (i.e., 4 g OM kg^{-1}). Halting tillage on soils with low OM contents or poor physical structure improved soil conditions after three years and significantly increased yields compared to tilled fields (Griffith et al., 1988). Recently, Pittelkow et al. (2015a,b) performed a global meta-analyses on soil tillage and crop rotation practices, analyzing more than 600 studies in 63 countries. They reported yield differences among tillage practices tended to be the largest during the first 1–2 year of treatment establishment for both corn and soybean. However, yield differences either slightly reduced or became negligible in the following years. Coupling this information with the vast literature of tillage effects on soil organic carbon (SOC) and erosion rates allow scientists to build inferences and hypotheses as to long-term tillage outcomes. Annual reports from U.S. state agricultural experiment stations as early as the mid 1800′s have indicated the role of soil tillage on soil erosion, loss of OM content, and the subsequent consequences to crop yields (Lee, 1849; Waters, 1888; Sewell, 1919). Since these early reports, the crop industry has dramatically evolved alongside the science in terms of tillage philosophy, equipment designs and options, alternative methods for controlling weeds, planter capabilities, plant genetics, and society's awareness of soil and water conservation (Tull, 1829; Sewell, 1919; Sprague, 1952; Van Doren et al., 1984; Triplett and Dick, 2008). These advances in science, philosophy, and technology have increased corn and soybean yield potentials five-fold and two-fold, respectively, and narrowed yield gaps (i.e., difference between actual yields and potential yields) with new high-yielding plant varieties and agronomic practices (Fischer, 2015). For an example, prior to 1950, corn and soybean yields rarely exceeded 2 and 1.5 Mg ha^{-1}, respectively (USDA-NASS, 1950), however, in recent years, producers in the Midwestern U.S. can expect 10–13 Mg ha^{-1} of corn and 2.7–3.3 Mg ha^{-1} of soybean on a yearly basis (USDA-NASS, 2015). The increase in yield potentials coupled with decreased yield gaps presents a valuable opportunity for producers to consider reducing their tillage operations or eliminating tillage completely in the interest of soil and water conservation while minimizing short- and long-term consequences to crop performance and stability.

Although plant breeders have published extensively on crop yield stabilities during the past century, similar evaluations of agronomic management practice effect on crop yield stability is much rarer (Piepho, 1998; Elias et al., 2016). Most of these studies have focused on seeding rates, row spacing, pesticides and herbicide application, and soil fertilizer amendments effects on crop yield stabilities, with few studies focused on tillage practices in corn systems of the Midwestern US (Piepho, 1998; Smith et al., 2007). Rusinamhodzi et al. (2011) performed a meta-analysis of 26 short- and long-term studies across the world with rain-fed corn data and performed a yield stability analysis. They report no observable differences in corn yield stability of reduced tillage practices to moldboard plowing. However, their analysis indicated that reduced tillage has a negative effect on corn yields as compared to plowing if corn is produced without a crop rotation, but positive effect on corn yields when corn is rotated with other crops. Pedersen and Lauer (2003) also reported that soybean yield stability was not affected by tillage practices during a 4-year study in Wisconsin. However, Verhulst et al. (2011) reported that corn yields stabilities were higher in NT fields as compared to conventional tilled fields in Mexico, which they contributed to better soil water conservation during drought years. Pan et al. (2009) reported increased cereal yield stabilities across China during 1949–1998 for fields that increased soil organic matter. Additionally, other crops such as rice, sugar beet, and wheat have been reported to have positive gains in crop yield stability in reduced till or NT practices as compared to conventional tillage or puddling of soil, which were further enhanced when the crops were included in a rotation (Raman et al., 2011; Gotze et al., 2017). However, Cox (1991) reported that differences in wheat yield stability among tillage practices are observable in some cultivars and not others for studies done in North Dakota.

These studies report crop yield stabilities via regression methods similar to, or derived from Eberhart and Russell (1966) and Finlay and Wilkinson (1963); which have been widely used in the scientific literature over the past century for evaluating crop yield stability for genetic by environment (GE) and management by environment (ME) interactions (Piepho, 1998; Tollenaar and Lee 2002; Edgerton et al., 2012; Elias et al., 2016). Eberhart and Russell (1966) and Finlay Wilkinson (1963) provided estimates of 'desired stability parameters' by regressing crop yields of a particular crop variety on an 'environmental index'. However, Eberhart and Russell (1966) extended the use of the regression's residuals to quantify the unpredictable portion of crop yield stability. These type of parametric analyses allow a simple,