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When does no-till yield more? A global meta-analysis

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ABSTRACT

No-till agriculture represents a relatively widely adopted management system that aims to reduce soil erosion, decrease input costs, and sustain long-term crop productivity. However, its impacts on crop yields are variable, and an improved understanding of the factors limiting productivity is needed to support evidence-based management decisions. We conducted a global meta-analysis to evaluate the influence of various crop and environmental variables on no-till relative to conventional tillage yields using data obtained from peer-reviewed publications (678 studies with 6005 paired observations, representing 50 crops and 63 countries). Side-by-side yield comparisons were restricted to studies comparing conventional tillage to no-till practices in the absence of other cropping system modifications. Crop category was the most important factor influencing the overall yield response to no-till followed by aridity index, residue management, no-till duration, and N rate. No-till yields matched conventional tillage yields for oilseed, cotton, and legume crop categories. Among cereals, the negative impacts of no-till were smallest for wheat (−2.6%) and largest for rice (−7.5%) and maize (−7.6%). No-till performed best under rainfed conditions in dry climates, with yields often being equal to or higher than conventional tillage practices. Yields in the first 1–2 years following no-till implementation declined for all crops except oilseeds and cotton, but matched conventional tillage yields after 3–10 years except for maize and wheat in humid climates. Overall, no-till yields were reduced by 12% without N fertilizer addition and 4% with inorganic N addition. Our study highlights factors contributing to and/or decreasing no-till yield gaps and suggests that improved targeting and adaptation, possibly including additional system modifications, are necessary to optimize no-till performance and contribute to food production goals. In addition, our results provide a basis for conducting trade-off analyses to support the development of no-till crop management and international development strategies based on available scientific evidence.

1. Introduction

Feeding a growing world population with increasing dietary preferences for resource-intensive food products is a major challenge facing humanity (Foley et al., 2011). It has been suggested that maintaining the increases in yields achieved over the past half-century, itself a challenge, will be insufficient to meet future global food demand (Grassini et al., 2013). Meanwhile, increased crop productivity is only one aspect of meeting future food security goals, and concerns over agricultural sustainability are greater than ever, with evidence that intensive conventional production practices can have severe negative environmental consequences (Foley et al., 2011; Godfray and Garnett, 2014; Tilman et al., 2011). High-yielding, conventional agricultural systems are often characterized by high rates of fossil fuel energy consumption, excessive nutrient use, soil degradation, and water pollution (Foley et al., 2011). Thus a global imperative has been set forth – to produce more with less – and various strategies are being promoted to achieve these goals.

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No-till[1] agriculture represents a relatively widely adopted soil management practice. The origins of no-till agriculture lie in the dustbowl of the 1930s in USA, where severe erosion of degraded soils occurred over large areas of agricultural land, prompting a shift toward reduced tillage practices (Six et al., 2002; Derpsch et al., 2010). However, the majority of no-till expansion worldwide has occurred since the mid- to late-1990s, facilitated by the use of herbicides and improved no-till technologies (Derpsch et al., 2010). From both an agricultural research and development standpoint, no-till has received much attention as a potential solution to the large challenges described above.

Research on no-till has often occurred within the context of conservation agriculture (CA). Conservation agriculture represents a set of three crop management principles: minimum soil disturbance (including no-till), crop rotation, and residue retention/permanent soil cover (FAO, 2011). For a thorough discussion of how CA farming systems are implemented in different parts of the world including site-specific benefits, factors enabling adoption, and key challenges, the reader is directed to several recent special journal issues and books (Serraj and Siddique, 2012; Stevenson et al., 2014; Jat et al., 2014a).

The environmental and economic benefits of no-till implemented as the core principle of CA are well-documented (Hobbs et al., 2008). One of the key factors underlying the success of no-till in combination with the other CA principles is that it conserves soil resources by reducing wind and water erosion (Verhulst et al., 2010). No-till in the context of CA can also lead to improvements in soil quality by improving soil structure and enhancing soil biological activity, nutrient cycling, soil water holding capacity, water infiltration and water use efficiency (Six et al., 2002; Hobbs et al., 2008; Verhulst et al., 2010; FAO, 2011). Importantly, no-till in combination with the other two CA principles can reduce production costs and increase profitability, often attributed to decreases in energy and labor consumption compared to conventional systems (Erenstein et al., 2012). Economic benefits coupled with reduced soil erosion are likely the main reasons for no-till adoption (Derpsch et al., 2010). Although there is the potential for no-till to contribute to soil C sequestration among other ecosystem services such as reduced soil greenhouse gas emissions in specific circumstances (Six et al., 2004; van Kessel et al., 2013), recent reports indicate that these benefits may not be as widely observed as previously thought (Powlson et al., 2014; Palm et al., 2014).

In terms of how no-till influences crop productivity, there is little consensus as to whether yields are maintained or yield increases or decreases can be expected despite these practices being widely investigated (Brouder and Gomez-Macpherson, 2014; FAO, 2011; Giller et al., 2009). Several previous analyses have summarized the yield impacts of various forms of no-till (including no-till implemented as the core principle of CA) on a crop-specific or regional basis, concluding that yields often increase under water-limited conditions (Farooq et al., 2011; Rusinamhodzi et al., 2011). In contrast, a number of reviews have shown that no-till practices can reduce crop productivity due to the potential for soil waterlogging and/or cooler soil temperatures which can inhibit crop establishment, compaction which can affect root growth, or altered soil fertility requirements which may lead to nutrient deficiencies (Alvarez and Steinbach, 2009; Ogle et al., 2012; Van den Putte et al., 2010). While recent work has synthesized data across large numbers of cropping systems and wide geographical areas (Brouder and Gomez-Macpherson, 2014; Toliver et al., 2012; Ogle et al., 2012; Van den Putte et al., 2010; Scopel et al., 2013; Pittelkow et al., 2015), no-till yield outcomes have not been quantified at a global scale across a range of important agronomic and environmental factors.

In light of increasing support for no-till as a tool to address global food security and sustainability goals, we used meta-analyses to summarize previous studies investigating the effects of no-till on crop yields. At a global scale, our objectives were to (i) evaluate the influence of crop and environmental variables on no-till productivity and (ii) identify factors contributing to no-till yield gaps to provide the scientific support for evidence-based crop management and international development strategies.

2. Materials and methods

2.1. Data collection

Following the approach reported by Pittelkow et al. (2015), we conducted a literature search to collect yield data from publications reporting side-by-side comparisons of conventional and no-till practices. Unlike in the data analyzed in Pittelkow et al. (2015), individual studies were not required to report residue management or crop rotation practices to be included in the database. Thus, the present analysis contained 68 additional studies (542 observations) compared to Pittelkow et al. (2015). A thorough description of no-till definitions used in this study and the specific paired yield comparisons extracted from publications are provided in Pittelkow et al. (2015). In brief, no-till treatments consisted of zero tillage immediately before crop establishment for a given growing season (that is, reduced tillage treatments such as strip-tillage were not considered). A reference list for publications included in the present analysis is provided as Supplementary Material.

Crops were grouped into the following categories: maize, wheat, miscellaneous cereals (barley, millet, oat, rye, sorghum, tef, triticale), legumes (alfalfa, bean, chickpea, clover, groundnut, lentil, lupin, pea, peanut, pigeonpea, soybean, vetch), oilseeds and cotton (canola, cotton, flax, linseed, mustard, safflower, sunflower, yellow sarson), rice, miscellaneous (broccoli, coffee, cucumber, lettuce, mustard leaf, pepper, squash, tobacco, tomato, watermelon), and root crops (cassava, cocoyam, potato, sugar beet, sweet potato, taro, yam). Cotton was grouped with oilseeds as it is also a dicot that can be used for oil production and there were not sufficient observations available for it to represent its own category ($n = 188$). Sugarcane, ryegrass, and canary seed (representing only 12, 4, and 1 observation(s), respectively) were not included in these crop categories.

When assessing yield responses by latitude, categories for tropical, subtropical, and temperate latitudes were defined as 0–20, 20–30, and 30–66 degrees, respectively. For studies that reported N management information, the source of N fertilizer was recorded as organic, inorganic, or integrated (i.e. both organic and inorganic N). Inorganic N rates were determined by summing individual preseason and within-season N applications. In a small number of cases where organic or inorganic N was applied to a previous cover crop or crop other than the no-till vs. conventional tillage yield comparison, these N sources were not included. If a range of N rates was reported in a study across sites, crops, or years, values were only included in the database if exact N rates were provided or if the range of values was smaller than 15 kg N ha^{-1} in which case the average N rate was used. When a range of N rates were applied in sub-plot N trials, but only the main effects of tillage were presented, N rates for those observations were not entered into the database. When analyzing the overall effects of N source and inorganic N rate across crops, legumes were not included.

[1] Despite an increasing focus on no-till globally, it needs to be acknowledged that the term 'no-till' is not always used consistently. In order to appropriately define the context for this study, a brief discussion of no-till terminology has been supplied as Supplementary Material. In addition, a discussion of specific study considerations and limitations is provided in Section 4.4. Our analysis aimed to quantify the effects of no-till rather than systems-level modifications to a cropping system as outlined by Derpsch et al. (2014).