Field Crops Research 183 (2015) 204–210

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Nitrogen fertilization reduces yield declines following no-till adoption

Mark E. Lundy[a,b,*], Cameron M. Pittelkow[c], Bruce A. Linquist[a], Xinqiang Liang[d], Kees Jan van Groenigen[e], Juhwan Lee[f], Johan Six[f], Rodney T. Venterea[g,h], Chris van Kessel[a]

[a] Department of Plant Sciences, University of California, Davis, CA 95616, USA
[b] University of California, Division of Agriculture and Natural Resources, Cooperative Extension, USA
[c] Department of Crop Sciences, University of Illinois, Urbana, IL 61801, USA
[d] College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China
[e] Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, AZ 86011, USA
[f] Department of Environmental Systems Science, Swiss Federal Institute of Technology, ETH-Zurich, Zurich 8092, Switzerland
[g] USDA–ARS, Soil and Water Management Unit, St. Paul, MN 55108, USA
[h] Department of Soil, Water, and Climate, University of Minnesota, St. Paul, MN 55108, USA

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form 17 July 2015
Accepted 19 July 2015
Available online 14 August 2015

Keywords:
Tillage
Nitrogen fertilizer
No-till duration
Residue
Rotation
Tropical/subtropical
Temperate
Meta-analysis

ABSTRACT

Conservation agriculture (CA) has been promoted as a method of sustainable intensification and climate change mitigation and is being widely practiced and implemented globally. However, no-till (NT), a fundamental component of CA, has been shown to reduce yields in many cases. In order to maintain yields following adoption of CA, it has been recently suggested that fertilizer application should be an integral component of CA. To determine the contribution of nitrogen (N) fertilizer in minimizing yield declines following NT implementation, we assessed 2759 paired comparisons of NT and conventional tillage (CT) systems from 325 studies reported in the peer-reviewed literature between 1980 and 2013. Overall, we found that NT yields decreased −10.7% (−14.8% to −6.5%) and −3.7% (−5.3% to −2.2%) relative to CT in tropical/subtropical and temperate regions, respectively. Among management and environmental variables that included: the rate of N fertilization; the duration of the NT/CT comparison; residue, rotation, and irrigation practices; the crop type; and the site aridity, N rate was the most important explanatory variable for NT yield declines in tropical/subtropical regions. In temperate regions, N fertilization rates were relatively less important. NT yield declines were most consistently observed at low rates of N fertilization during the first 2 years of NT adoption in tropical/subtropical regions. Applications of N fertilizer at rates of up to 85 ± 12 kg N ha^{-1} yr^{-1} significantly reduced NT yield declines in these scenarios. While this result should not be viewed as a rate recommendation, it does suggest that farmers applying rates of N fertilizer that are low for their specific system will, on average, see higher NT yields if they increase application rates. In addition, when crop rotation was not practiced or residues were removed from the field, NT yield declines were magnified by low rates of N fertilization in tropical/subtropical regions. These results, based on a global data set and across a broad range of crops, highlight the importance of N fertilization in counteracting yield declines in NT systems, particularly in tropical/subtropical regions.

1. Introduction

Conservation agriculture (CA) is a suite of management practices designed to sustainably intensify the productivity of farming systems (FAO, 2008). Currently, an estimated 125 M ha (9% of all global cropland) are under some form of CA management (Friedrich et al., 2012; Kassam et al., 2012), and CA is being actively promoted in sub-Saharan Africa (SSA) as part of "Climate Smart" agricultural efforts (FAO, 2013). Conservation agriculture is based on three key principles: (1) limited or zero soil disturbance (i.e. minimum tillage or no-till (NT)), (2) crop residue retention to ensure maximum soil cover, and (3) crop rotation (FAO, 2013; Hobbs et al., 2008). Multiple biophysical benefits from CA have been reported in a wide array of cropping systems across the globe. Among the most widely documented of these benefits are erosion control (Lal, 1998; Scopel et al., 2005), soil water conservation (Hobbs et al., 2008; Thierfelder and Wall, 2009, 2010), and improved crop water use efficiency

* Corresponding author at: Department of Plant Sciences, University of California, Davis, CA 95616, USA.
E-mail address: melundy@ucdavis.edu (M.E. Lundy).

http://dx.doi.org/10.1016/j.fcr.2015.07.023
0378-4290/

(Hobbs et al., 2008; Thierfelder and Wall, 2009, 2010). In addition, some authors have reported sustained or increased crop productivity resulting from the implementation of CA (Hansen et al., 2012; Rusinamhodzi et al., 2011; Ngwira et al., 2012).

Yet, recent work by Pittelkow et al. (2015a) suggests that yield changes due to the implementation of CA principles are usually negative, and depend upon the duration and extent to which all three CA principles are enacted as well as on the climate where CA is practiced. Indeed, despite the documented benefits of CA, its adoption has been more widespread in developed countries and temperate regions (Friedrich et al., 2012), and its broad applicability to the diverse cropping systems around the globe continues to be a topic of debate. For example, Giller et al. (2009) argued that the ecological and socio-economic conditions within SSA are often unsuitable to justify the implementation of CA. Among the concerns raised were the potential for yield reductions following CA implementation and the limited availability of crop residues in SSA cropping systems. Vanlauwe et al. (2014) echoed parts of this argument in a recent call for the application of fertilizer to be considered a “fourth principle” for CA in SSA. They argued that: (1) a primary reason for limited CA adoption by SSA smallholders is the lack of organic resources (e.g. crop residues) required to achieve sufficient soil cover; (2) application of adequate fertility can remedy this lack of soil cover; and (3) promoting a supply chain of fertilizer available at affordable prices should go hand-in-hand with promoting CA. Sommer et al. (2014) agreed that fertilizer inputs are crucial to the successful implementation of CA, but disagreed that this was grounds for articulating it as a fourth principle. These authors argued that insufficient fertilizer use is not unique to CA systems in SSA and that nutrient management is no more serious of a problem than lack of crop rotation or residue retention in CA systems. Meanwhile, Lal (2015) included “improving soil fertility by integrated nutrient management” as one of four CA principles in a recent overview of CA research.

To shed light on the discussion regarding the relative importance of nitrogen (N) fertilizer in the successful implementation of CA systems, we supplemented the data reported by Pittelkow et al. (2015a) with N management information and measured the proportional contribution of N fertilizer rates to NT/CT yield differences following NT implementation in both tropical/subtropical and temperate regions. Further, we evaluated mixed-effects models to determine whether and how the rate of N fertilization interacts with other management variables and affects the relationship between NT and CT yields in these regions.

2. Materials and methods

2.1. Data collection

As detailed in Pittelkow et al. (2015a), we searched the peer-reviewed literature for publications investigating the effects of NT on crop yields from January 1980 to May 2013 using Scopus (Elsevier, Amsterdam, Netherlands). Search terms included ‘tillage’, ‘no till’, ‘zero till’, ‘direct drill*’, or ‘conservation ag*’ in the article title and ‘yield’ in the article title, abstract, or keywords. The publications that resulted from this search were screened to ensure that only studies with side-by-side comparisons of NT and CT yields without confounding effects were included. Studies reporting differences in management between NT and CT treatments such as variations in residue management, crop rotation, N fertilization, or irrigation were not included (e.g. a study comparing yields from a NT treatment with residues retained to a CT treatment with residues removed would have been excluded). The lone exception was that NT and CT treatments were not required to have the same weed management because the different tillage approaches tend to result in distinct weed recruitment patterns (Farooq et al., 2011). Site characteristics including crop type, location, aridity index, duration of the NT/CT comparison, rotation history, and residue management were recorded. As reported by Pittelkow et al. (2015a), information for continuous and categorical variables was extracted from the Materials and Methods section of publications, and to a lesser extent was inferred from discussions of crop management details found in the Introduction or Discussion sections.

For the purposes of the present study, N fertilizer management information was recorded from each study when available. Observations from studies that reported a range of N rates across sites, crops, or years, were only included in the database if exact rates were provided or if the range of values was smaller than 15 kg N ha^{-1} (for these studies, the midpoint was chosen). When the main effects of tillage were presented across a range of N rates applied in sub-plots, N rates were not entered into the database. In addition, only observations where inorganic forms of fertilizer were used or where no fertilizer was applied were included.

The database was further confined to: (1) observations for which crop rotation information was available (observations with a preceding cover crop were categorized as having a crop rotation); (2) observations for which the duration of the NT/CT yield comparison was reported; (3) observations from plots where residues were not reported to have been burned (4) observations on non-legume crops. Finally, the data was partitioned into tropical/subtropical (latitude zones: ≤30°N or ≥−30°S) or temperate (latitude zones: >30°N or <−30°S) regions. A total of 2777 observations from 325 studies were initially included. Following the removal of extreme values (described below) a total of 2759 observations from 325 studies were analyzed; the included studies can be found in Supplementary Table S1. Summary statistics regarding N fertilizer rates, climate regime, duration of the NT/CT comparison, residue management (retained/removed/not stated), crop rotation prevalence, and irrigation prevalence in the evaluated studies are displayed in Table 1.

Supplementary Table S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fcr.2015.07.023

2.2. Data analysis

To determine the effect of tillage practices on yield, response ratios were calculated as the natural log of the ratio of paired NT to CT yields, $\ln[\text{yield}_{NT}/\text{yield}_{CT}]$ (Hedges et al., 1999). Individual observations were assigned weights based on the number of replications associated with the observation, with weights = $(n_{CT} \times n_{NT})/(n_{CT} + n_{NT})$, where n_{CT} and n_{NT} are the number of replicates for CT and NT treatments, respectively (Adams et al., 1997). Where more than one observation from a study was included, weights were divided by the total number of observations from that study. Extreme values were identified as those ±5 standard deviations (SD) from the weighted mean and removed from the data set, which totaled 0.9% and 0.4% of the observations in the tropical/subtropical and temperate data sets, respectively. Bootstrapping procedures were used to generate 95% confidence intervals (CI) for weighted mean effect sizes using the “boot” package in R (version 3.0.2) with 4999 iterations (R Core Team, 2013). Weighted mean effect sizes were considered significantly different from zero and from other values if the CI(s) did not overlap. For ease of interpretation, results were back-transformed and reported as percentage change in yield for NT relative to CT practices.

Using the yield response ratio as the dependent variable and with observation weights included in the fitting process, the relative importance of the independent variables was determined via