Agriculture, Ecosystems and Environment 216 (2016) 155–165

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Conservation tillage and sustainable intensification of agriculture: regional vs. global benefit analysis

Nikolaus J. Kuhn[a], Yaxian Hu[a,*], Lena Bloemertz[a], Jin He[b], Hongwen Li[b], Philip Greenwood[a]

[a] Physical Geography and Environmental Change Research Group, University of Basel, Klingelbergstrasse 27, Basel 4056, Switzerland
[b] Conservation Tillage Research Center, China Agricultural University, Qinghua East Road 17, Beijing 100083, China

ARTICLE INFO

Article history:
Received 20 June 2015
Received in revised form 30 September 2015
Accepted 1 October 2015
Available online 19 October 2015

Keywords:
Conservation tillage
Carbon sequestration
Food security
Global averaging
Spatial weighting

ABSTRACT

Climate change is expected to affect both the amount of global crop production, and annual variability in food supply. Agriculture is a major source of greenhouse gas emissions, but also considered to mitigate climate change. Conservation tillage, as a climate-smart agricultural practice, is repeatedly reported to mitigate net greenhouse gas emissions by increasing soil organic carbon (SOC). However, with reduced tillage, less litter is moved from the surface deeper into the soil profile, so SOC increase is very likely constrained to topsoil layers. Further adaptation benefits, such as increasing crop yield and resilience to famine, have recently been questioned after averaging yields from field studies. However, such global averaging masks the geographic extent individual studies apply to. This paper attempts a holistic regional analysis on the benefits of conservation tillage, in particular its fundamental principle no-tillage (NT), on the Chinese Loess Plateau. Based on a review of almost 20 years of conservation tillage plot experiments, the potential of NT to increase SOC stocks and to adapt to lower but more variable rainfall in the future has been assessed. The results show that the difference of total SOC stocks between NT and CT decreased with soil depth, confirming that the SOC benefits of NT are concentrated to the immediate topsoil still subject to direct seeding. The topsoil achieved maximum SOC stocks after about 10 years of NT. Crop yields from NT increased by up to 20% for years with average and below average precipitation, demonstrating the advantages of NT in stabilizing crop yields in dry years. However, the results in previous reports are not weighted by the actual spatial extent of drylands and humid regions after counting individual plot studies. As a consequence of such global and unweighted averaging, the benefits from NT to increase SOC stocks are likely to misrepresent the actual impact. Therefore, given the size of the Loess Plateau and its relevance for food security in China, our analysis illustrates the need to assess the benefits of a tillage and residue management system for each combination of eco-region and farming practice, weighted by their area and the affected population, rather than just using a global average for policy development on sustainable productivity.

1. Introduction

Climate change is expected to affect global food security by changing both spatial and temporal patterns of yields (Wheeler and von Braun, 2013). Agriculture also causes emissions of 500 Tg C to the atmosphere per year (Lal, 2004a). In particular, the use of nitrogen fertilizers contributes 187–224 Tg CH_4 and 1.7–4.8 Tg N_2O per year (Ipcc, 2013). Meanwhile, agriculture could also mitigate climate change (Vermeulen et al., 2012), most notably by enhancing soil organic carbon (SOC) on degraded agricultural lands. The contribution is equivalent to 50–60% of the 42–78 Pg C of soil carbon released from human-induced land use change over 25–50 years (Ipcc, 2013). In particular, conservation tillage, as a manner of climate-smart agriculture practice, is repeatedly reported to mitigate climate change by reducing net greenhouse gas emissions (Lal, 2004b; X. Wang et al., 2008; He et al., 2010b; Li et al., 2012). Conservation tillage may also contribute to climate change adaptation by increasing or at least limit the decline of crop yields in dry years (FAO, 2011), and thus help to strengthen resilience to famine by ensuring regional access to affordable food in dry years/dry regions (Cavatassi et al., 2011). Conservation tillage also has co-benefits that include increased resistance to soil erosion (Pimentel et al., 1995; Leys et al., 2007; Knapen et al., 2008), improving water use efficiency (Bai et al., 2009; He et al.,

* Corresponding author.
E-mail address: yaxian.hu@unibas.ch (Y. Hu).

http://dx.doi.org/10.1016/j.agee.2015.10.001
0167-8809/

2010a; Li et al., 2011), and reducing labor and energy inputs (Tullberg et al., 2007).

A fundamental principle of conservation tillage is no-tillage (NT), which minimizes mechanical disturbance of soil, limiting macro-aggregate destruction, and thereby reducing exposure of soil organic matter to mineralization (Rhoton et al., 2002; Six et al., 2004; Liu et al., 2014). While conservation tillage is in general considered to help increase crop yields and sequestrate atmospheric SOC (as discussed above), some recent papers argued that the potential contribution of NT to climate change mitigation and food security is more limited than initially thought. For instance, Powlson et al. (2014) argued that the role of NT in climate change mitigation is overestimated by at least one order of magnitude if applying a modest annual carbon accumulation rate (0.3 Mg C ha^{-1}) to the global area under cereal crops. In addition, after averaging results from pairwise plot experiments on various types of crop reported in 610 papers from 63 countries, Pittelkow et al. (2014) concluded that potential contributions of no-tillage soil management to sustainable intensification of agriculture and food security are more limited than often assumed, overall leading to a 5.7% decline of global crop yields.

These recent negative assessments of NT benefits are based on averaging yields from plot and field studies (Pittelkow et al., 2014; Powlson et al., 2014). These reports point out that the effects of NT vary with climate. Consequently, a diagnosis of the regional ecology and farming system is required. However, interpretation of globally averaged values does not reflect the potential sum of regional benefits of NT appropriately, because plot and field results have not been weighted by the geographic area individual studies apply to (e.g., in Pittelkow et al. (2014)). In addition, assessing the full benefits of NT requires an understanding of all impacts for each agro-eco-region, including future trends of climate change, soil quality changes on crop production and food security. This paper attempts such a holistic review of the benefits of conservation tillage on the Chinese Loess Plateau, including SOC, crop yields and their variability, as well as an outlook on future soil quality, to assess the need for region-specific assessments of the benefits of conservation tillage.

The Chinese Loess Plateau, located in the mid-upper reaches of the Yellow River catchment (Fig. 1), covers an area of 0.63 million km^2 (Tang and Nan, 2012). Eighty percent of the 0.17 million km^2 of cropland on the Loess Plateau (corresponding to 10% of US cropland) are used for small-scale rainfed wheat, corn, and millet production for regional or national consumption (Ostwald and Chen, 2006). While still a regional study, the Loess Plateau has a national relevance for food security in China where the number of undernourished people declined from 21% in 1990 to 12% in 2013 (FAO, 2013). However, the limited amount of arable land and scarce water supplies will remain a challenge for further improvements. The average yields on the Loess Plateau are 3.16 t ha^{-1} for wheat (corresponding to 60% of US crop yields) (Zhang and Liu, 2005). However, after centuries of deforestation of the hilly landscape, over-grazing, low vegetation cover, highly erodible loess soil, and heavy rain storms in summer, the Loess Plateau has become one of the most severely eroded areas in the world (Zhang and Liu, 2005; Hessel et al., 2003; He et al., 2004; Deng et al., 2010). In addition, the Loess Plateau has been exposed to a steadily increasing temperature as well as highly variable, but slightly decreasing

Fig. 1. The map of China, with the Loess Plateau delineated in bright yellow color. Map source: Australian Center for International Agricultural Research Project: Regional impacts of re-vegetation on water resources of the Loess Plateau, China and the Middle and Upper Murrumbidgee Catchment, Australia.