Conservation tillage enhances productivity and decreases soil nitrogen losses in a rainfed agroecosystem of the Loess Plateau, China

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Introduction

Over the last several decades, synthetic nitrogen (N) fertilizer use has greatly contributed to the enhancement of food production and hence alleviation of hunger in China. However, decades of N fertilizer overuse, especially in dryland agriculture systems, have resulted in serious environmental damages, mainly through disturbing the balance of N cycling of agroecosystems. N balance in agroecosystems provides a quantitative framework of N inputs and outputs and retention in the soil for assessing the sustainability of agricultural productivity, soil health, and environmental quality. Mechanical disturbance of soils significantly affects the intensity of N inputs and outputs, eventually determining differential N balance under different tillage practices such as zero-tillage and plough-tillage. The tillage practice affects farmland N inputs and fixation through various mechanisms, mainly including the fixation of fertilizer N, transformation of N forms, and N feedback from crop roots.

Conservation tillage has been recommended as one of the effective soil management practices for mitigating the negative environmental effects of synthetic ammonia application and hence achieving cleaner agricultural production. However, information about how long-term conservation tillage affects agroecosystem nitrogen balance in dryland winter wheat-summer maize cropping is limited. Based on a long-term (>9 yr) field tillage experiment and in-situ observation, we assessed the effects of different tillage practices (i.e., chisel plough tillage (CPT), zero tillage (ZT), and conventional ploughing tillage (PT)) on soil nitrogen balance and crop productivity in the 2016–2017 and 2017–2018 growing seasons. We hypothesized that (i) long-term reduced tillage practices such as zero-till and chisel plough tillage would have an advantage in increasing crop grain N removal and soil N storage by decreasing soil N losses from gaseous emissions and hydrological leaching, compared with traditional plough tillage; (ii) long-term reduced tillage practices would achieve more sustainable agroecosystem N balance via enhancement of crop N uptake and soil N surplus, and reduction in soil N losses.

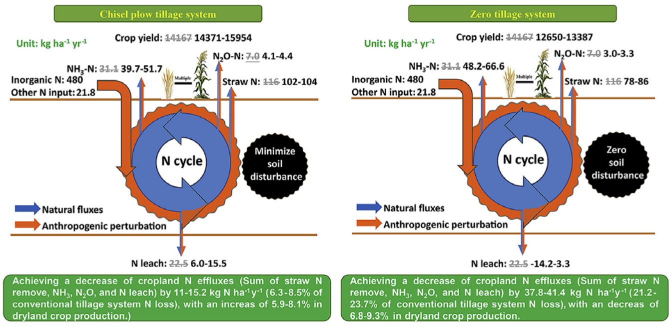

Fig.1 Soil nitrogen flow and nitrogen balance framework of long-term conservation tillage farmland

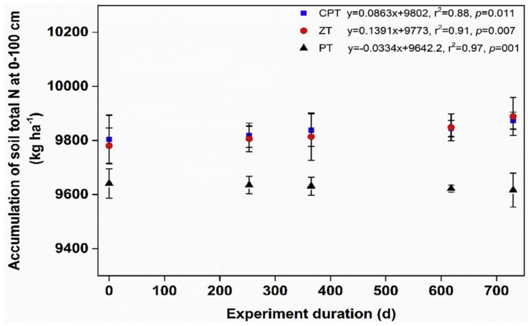

Fig.2 Rate of nitrogen change estimated in a linear regression analysis of soil total N in consecutive crop growing seasons

Main results

Each tillage practice was exposed to a local widely adopted N application rate (240 kg ha^{-1} yr^{-1}) in both seasons. Our results indicated that, compared with PT, CPT and ZT significantly ($P < 0.05$) reduced N2O emissions by 39.7% (2.8 kg N ha^{-1} yr^{-1}) and 55.3% (3.9 kg N ha^{-1} yr^{-1}), and N leaching by 52.3% (11.8 kg N ha^{-1} yr^{-1}) and 147.7% (33.3 kg N ha^{-1} yr^{-1}) across the two growing seasons, respectively.

CPT significantly enhanced crop aboveground N uptake by 4.0%, and increased the annual crop yield by 5.9–8.1% (0.8–1.2 t ha^{-1} yr^{-1}). Although CPT and ZT enhanced NH3 volatilization by 46.7% (14.6 kg N ha^{-1} yr^{-1}) and 84.3% (26.3 kg N ha^{-1} yr^{-1}), the total N losses under CPT and ZT were decreased on an average by 7.4% and 22.4%, respectively.

Overall, CPT and ZT significantly increased the accumulation of soil total nitrogen in the 0–100 cm layer by 34.8 and 54.1 kg N ha^{-1} yr^{-1}, respectively. Taking N inputs and outputs together, CPT achieved a lower N surplus mainly due to increased crop N harvest and reduced N losses including gaseous emissions and hydrological leaching. Our findings suggest that long-term chisel plough tillage in dryland agroecosystems could serve as a promising soil management practice in increasing crop productivity and maintaining sustainability through enhancing N removal from crop biomass and decreasing N losses via N2O emission and nitrate-N leaching.

Conclusions

- CPT practice significantly increased grain yields and grain N harvested.
- CPT and ZT significantly reduced the loss of N2O, NO3− leaching and straw N removal.
- Conservation tillage in drylands should mitigate risk of NH3 volatilization.
- Accumulation of soil total N in 0–100 cm layer remained increasingly in CPT and ZT.
- The CPT is a promising tillage practice for achieving cleaner production.

Significances and outlook

These findings can be expected to improve our understanding of how reduced tillage intensity affects the agroecosystem N balance and help identify optimal soil management practices in dry environments for sustainable production. However, conservation tillage significantly reduces total reactive N losses, with a greater the risk of ammonia volatilization. To support the large-scale promotion of conservation tillage, future research should explore means to reduce the risk of ammonia volatilization in conservation tillage systems without inhibiting crop yield.