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Short communication

Effect of full substituting compound fertilizer with different organic manure on reactive nitrogen losses and crop productivity in intensive vegetable production system of China

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ABSTRACT

How substituting compound fertilizer with organic manure affects crop productivity and reactive nitrogen (Nr) losses from vegetable production system during the cradle-to-gate life cycle is not well understood. We thus investigated the impact of substituting compound fertilizer with various organic manures (stored solid manure and composted manure) on spinach productivity, Nr losses (e.g. NH_3, N_2O, NOx, N-leaching) and yield-based Nr losses in Changsha, Hunan, China. We found that the application of stored solid manure and composted manure decreased the total Nr losses by 58.1% and 75.0%, respectively, compared with compound fertilizer, but the spinach productivity was also decreased by 27.9% and 16.4%. Overall, substituting compound fertilizer with organic manure decreased yield-based Nr loss by 41.9–70.1%. These results highlight that substituting compound fertilizer with organic manure, particularly composted manure, may be beneficial to the environment at the expense of vegetable productivity. Strategies should be developed to decrease Nr losses from N input without compromising productivity in intensive vegetable production system.

1. Introduction

Vegetable growing area occupied approximately 25 million ha in China in 2015 or 13.5% of the total cropping area (Huang et al., 2016; Mi and Shi, 2018). The nitrogen (N) input to intensive vegetable production is 3–6 times higher than staple food cultivation in China (Ju et al., 2006, 2009; Wang et al., 2015). This results in huge reactive N (Nr) losses including NH_3 volatilization, nitrous oxide (N_2O) and nitrogen oxide (NOx) emission, N leaching and runoff from vegetable cropping systems (Zhang et al. 2011, 2015; Fan et al., 2017). Excessive N application in vegetable systems also causes soil acidification and nitrate accumulation in soil profiles, which may pollute underground water (Zhang et al., 2015). Therefore, reducing Nr losses through adopting optimal N fertilizers management were critical for improving vegetable productivity and mitigating environmental Nr pollution in the vegetable-cropping systems (Ju et al., 2009; Fan et al., 2017, 2018).

Many N management practices have been developed to reduce Nr losses, such as optimizing N fertilizers input based on soil N tests (Chen et al., 2014; Xia et al., 2016), applying biochar (Li et al., 2017) and nitrification inhibitor with N fertilizer (Lam et al., 2018). Substituting chemical fertilizer with organic manure may also promote crop productivity, crop N uptake (Zhou et al., 2016; Xia et al., 2017), and consequently reducing various the Nr emissions (Gu et al., 2016). This is particularly important in China where the current recycling rate of livestock manure to cropland crop is low (43%), which poses a great potential for enhancing the further use of potential livestock manure (Gu et al., 2015). While a few studies have reported the impact of organic manure on crop productivity and Nr loss (Cui et al., 2013; Xia et al., 2017), the information on impacts of various organic manure on these variables is scarce, especially in the intensive vegetable production systems. In addition, most of studies mainly focused on the impact of substituting compound fertilizer with organic manure on N loss during the vegetable growth stage but neglecting the N emission sourced from the fertilizer production, transportation process (Holly

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Table 1
Basic physical and chemical characteristics in stored solid manure (T-MSS) and composted manure (T-MC).

Type	Water content(%)	Organic matter(%)	pH	TN (g/kg DW)	TC (g/kg DW)	TP (g/kg DW)	TK (g/kg DW)
T-MSS	53.1	82.7	7.8	29.2	199.5	16.5	10.6
T-MC	51.6	80.8	8.4	27.0	177.0	23.4	16.9

Note: T-MSS, stored solid manure (T-MSS); T-MC, composted manure; TN, total nitrogen; TC, total carbon; TP, total phosphorus; TK, total potassium.

et al., 2017; Xia et al., 2017; Zhang et al., 2018). Overall, cradle-to-gate life cycle assessment is rarely performed on how substituting fertilizer with various organic manures affects N loss and vegetable productivity.

Here, we conducted a field experiment to estimate the overall impact of substituting compound fertilizer with various organic manures (stored solid manure and composted manure) on spinach productivity and Nr losses (NH_3, N_2O, NOx, N-leaching) considering a cradle-to-gate perspective.

2. Materials and methods

Experiment (December 2013–February 2014) was conducted on a typical greenhouse spinach-cropping system in Changsha, Hunan Province, China (28°11′N, 113°5′E N). This region has a subtropical climate with an average annual temperature of 17.2 °C and average annual precipitation of 1361.6 mm. The topsoil (0–20 cm depth) has a pH of 7.3, and contains 11.1 g/kg organic matter, 1.5 g/kg total N, 19.4 g/kg total P, and 1.6 g/kg total K.

Spinach was sown on 1 December 2013 and harvested on 9 February 2014 following local practice. The experiment comprised three treatments with three replications totaling 9 experimental plots: compound fertilizer (T-CF, N:P:K = 16%:16%:16%), stored solid manure (T-MSS) and composted manure (T-MC). We applied basal fertilizer once at 273 kg N/ha in all three treatments after sowing the spinach seeds. T-MSS was a mixture of swine manure and spent mushroom compost (weight ratio: 6.2:1). T-MC was a mixture of swine manure, tobacco stem, bran, and reed chips (volume ratio: 2.2:2:1:1).

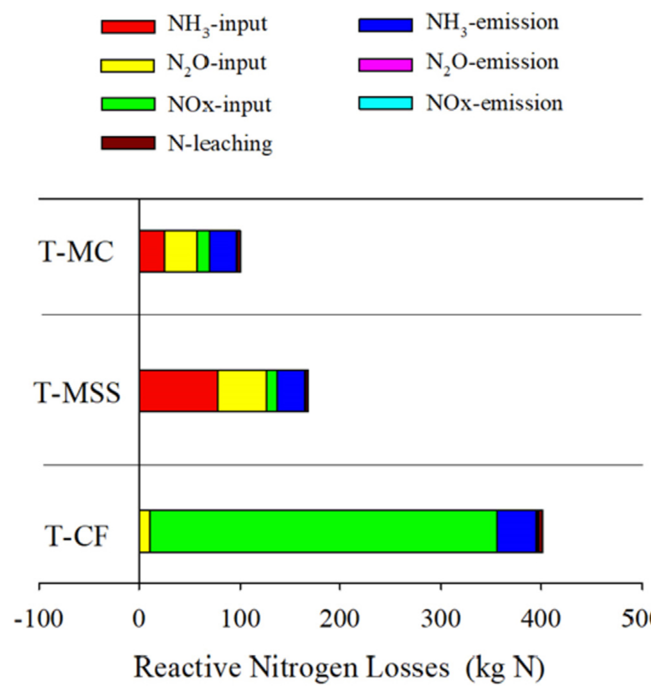

Fig. 2. Mean reactive nitrogen emissions (kg N) of different treatments during the total stage. Note: NH_3-input: NH_3 volatilization during fertilizer production in all three treatments; N_2O-input: N_2O emission during fertilizer production in all three treatments; NOx input: NOx emission during fertilizer production in all three treatments; NH_3-emission: NH_3 volatilization during spinach growth stage in all three treatments; N_2O-emission: N_2O emission during spinach growth stage in all three treatments; NOx-emission: NOx emission during spinach growth stage in all three treatments; N-leaching: N loss through leaching during spinach growth stage in all three treatments.

The detailed physical and chemical characteristics of proceeded T-MSS and T-MC were shown in Table 1.

We evaluated N_2O, NOx and NH_3 emissions during the spinach growth stage in all three treatments, production stage and

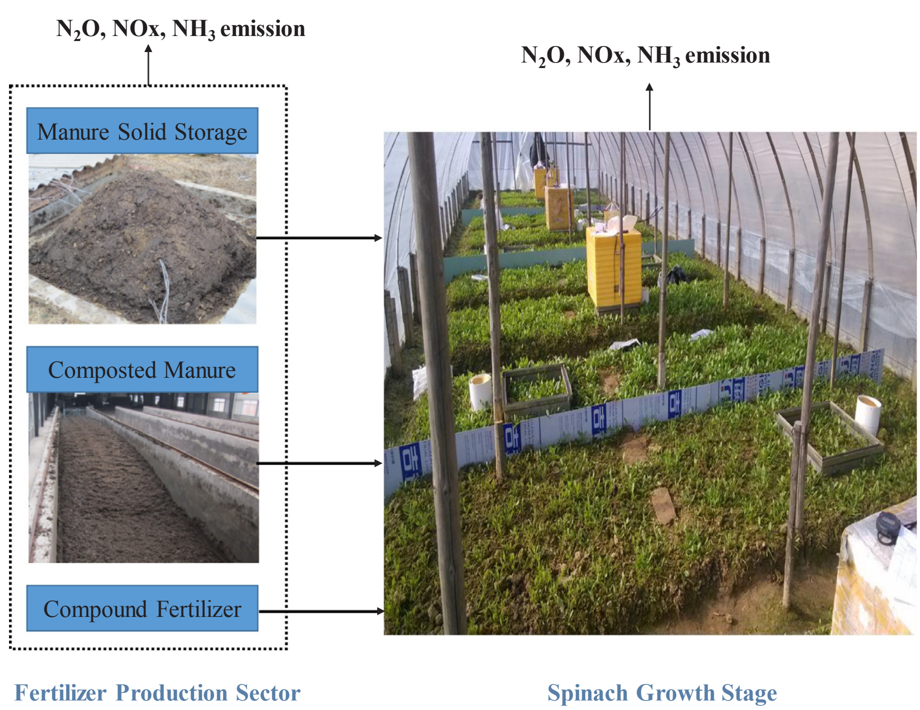

Fig. 1. Reactive nitrogen emissions in vegetable production system during the cradle-to-gate life cycle.

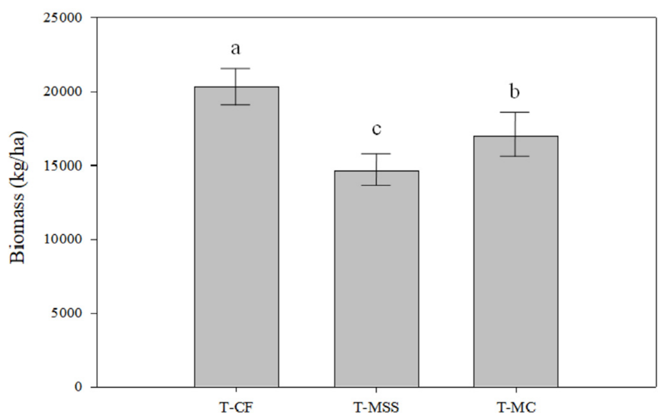

Fig. 3. The Spinach Productivity (kg/ha) of different management practices. Note: Different letters indicated that there was significant difference among treatments at the level of 0.05.

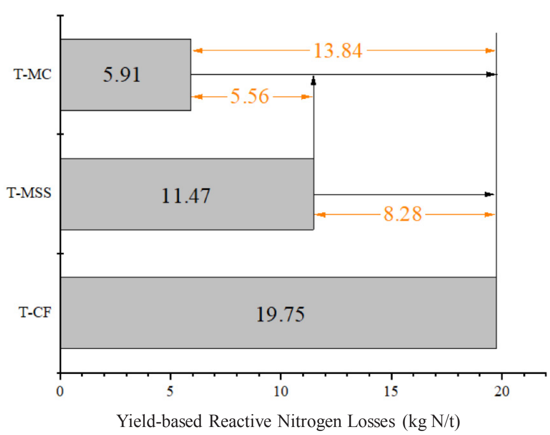

Fig. 4. The yield-based reactive nitrogen losses (kg N/t) of different management practices.

transportation stage of organic manure (Fig. 1). The emissions of N_2O, NOx and NH_3 were measured using static-chamber-gas chromatography, chemiluminescence absorption method and absorption by glycerol phosphate solution, respectively, following the procedures described in Yuan (2014). Gas sampling was conducted daily for the first two weeks after sowing, then once every two days 16–26 days after sowing, once every three days during 27–35 days after sowing, and once every four days during 35–50 days after sowing until harvest. In addition, we adopted the emission factors (EFs) to calculate the N_2O, NOx and NH_3 emissions during production stage and transportation stage of compound fertilizer (Xia et al., 2016; Xue et al., 2016; Wang et al., 2017a,b). During the spinach growth stage, N leaching was calculated based on the equations provided by Xia and Yan (2011). Nitrogen loss through runoff was negligible in this experimental site with flat a terrain.

Yield-based Nr losses (kg N/t) was obtained through total Nr emissions divided by total wet weight of spinach.

One-way analyses of variance (ANOVA) in SPSS ver. 19.0 statistical software was used to compare the differences of means for all parameters among all treatments. $p < 0.05$ denotes the significant difference among treatments, and vice versa.

3. Results and discussion

3.1. Nr emissions under T-CF, T-MSS and T-MC

During fertilizer production, compared with T-CF, Nr losses (NH_3 volatilization, N_2O emission and NOx) in T-MSS and T-MC were decreased by 61.5% and 80.6%, respectively. NH_3 (61.5% and 44.2%) volatilization and N_2O emission (38.5% and 54.8%) in T-MSS and T-MC were two main pathways of Nr loss (Fig. 2), which were also observed in previous studies (Yuan, 2014; Hou et al., 2015; Maurer et al., 2017; Wang et al., 2017a,b). This could be attributed to the 37% and 2% increase in NH_4^+-N and NO_3^-- N due to N contained in the manure relative to manure initial stage, respectively (Yuan, 2014). NOx-input was major Nr loss pathway (86%) in T-CF, which was attributed to coal combustion during the production of compound fertilizer (Khalil et al., 2006; Wang et al., 2017a,b). The N losses including NH_3-input and N_2O-input in T-MSS and T-MC was 12.2 times and 5.6 times higher than that in T-CF, respectively. However, NOx in T-CF was 29.3 times and 30.5 times higher than that in T-MSS and T-MC, respectively.

During the spinach growth stage, compared to T-CF, Nr losses in T-MSS and T-MC, were decreased by 31.7% and 33.2%, respectively (Fig. 2). Substituting compound fertilizer with various organic manure can decrease the emission of each Nr species, especially for NH_3 volatilization and N leaching which were the two major loss pathways. This could be partly due to the decrease in availability of N substrate through the stimulated microbial immobilization of mineral N (Zhou et al., 2016; Xia et al., 2017). However, spinach N uptake and N use efficiency were not improved after substituting compound fertilizer with different organic manure, which is inconsistent with other studies (Chivenge et al., 2011; Wang et al., 2015; Xia et al., 2017). This might be due to the excessive background soil N of this spinach farm with 0.003 g/kg NH_4^+-N and 0.001 g/kg NO_3^-- N.

The Nr losses during the cradle-to-gate life cycle in T-CF (401.5 kg N ha^{-1}) was 2.4 times and 4.0 times higher than that in T-MSS (167.5 kg N ha^{-1}) and T-MC (100.5 kg N ha^{-1}), respectively (Fig. 2). This difference was attributed to the increase in NOx loss during compound fertilizer production, and NH_3, N_2O and N-leaching during the spinach growth stage in T-CF.

3.2. Biomass and yield-based Nr losses under T-CF, T-MSS and T-MC

Compared with T-CF, spinach yield in T-MSS and T-MC were decreased by 27.9% and 16.4% (Fig. 3), respectively, which is consistent other studies (Chen et al., 2014; Pincus et al., 2016). The decrease in yield was attributed to the slower release of mineral N during decomposition of the organic manure, in comparison to compound fertilizer. The N supply from manure may therefore fail to satisfy the N demand of spinach during its rapid vegetative growth stage in the first 50 days (Siegfried et al., 2013; Chen et al., 2014; Pincus et al., 2016; Xia et al., 2017).

Yield-based Nr losses in T-CF, T-MSS and T-MC were 19.8 kg N/t, 11.5 kg N/t and 5.9 kg N/t, respectively (Fig. 4). This indicates that substituting compound fertilizer with organic manure reduced the yield-based Nr losses. The reduction was caused by the decrease in Nr emissions instead of an increase in spinach productivity.

4. Conclusion and implication

We found that substituting compound fertilizer with organic manure effectively reduced total Nr losses and yield-based Nr losses; the extent of reduction varied with manure types (stored solid manure or composted manure). However, substituting compound fertilizer with organic manure decreased spinach N uptake and productivity. Further research on how to promote both N uptake and productivity in spinach while minimizing Nr emissions should be warranted for better manure management in intensive vegetable production systems.

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