Effect of Different Tillage Methods on Soil Emissions of N$_2$O and Crop Yield in North China Grain Field

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Abstract. By analyzing the published literatures of wheat and maize fields in North China, the effects of different farming methods on N$_2$O emissions and crop yields in grain fields were determined. The results showed that in the North China grain field, the no-tillage technology reduced the N$_2$O potential in the wheat season, while the N$_2$O difference in the corn season using no tillage, conventional tillage, deep pine and alfalfa was not significant. Therefore, the implementation of no-till measures in the north wheat grain field in North China can reduce emissions and increase production, while the corn field suggests conventional tillage, deep pine or alfalfa cultivation on the basis of straw returning, which can stabilize production and reduce emissions.

1. Introduction
Greenhouse gas is an important source of climate warming and a range of environmental problems. N$_2$O is one of the greenhouse gases, and its concentration in the atmosphere is 20% higher than before industrialization and N$_2$O emissions from agricultural production account for 84% of total N$_2$O emissions [1-2]. The total grain output of the North China Plain accounts for 1/7 of the country’s total grain production area [3]. In order to obtain high yield, farmers put a lot of nitrogen fertilizer into the farmland. However, proper fertilizer application not only is unhelpful for crop growth, but also causes a series of environmental problems such as nitrogen wetting, soil and water eutrophication, and greenhouse effect [4-6]. The research on N$_2$O emission reduction in farmland in this area mainly focuses on fertilizer dosage and types, farming measures, long-acting fertilizers, and nitrogen control agents. Among them, fertilization and farming measures are important measures to improve wheat yield [7].

Many scholars have pointed out that reducing the nitrogen application rate in wheat/maize rotation in the region to 150-200 kg hm$^{-2}$ can ensure crop yield and reduce environmental pollution [4-6]. With the increase of nitrogen fertilizer application, the N$_2$O emission of soil increases linearly or curvily, so ensuring the appropriate amount of nitrogen fertilizer will help the region to reduce emissions and increase crop yield [8]. The relevant farming measures have not been conclusive about the reduction of
grain output and production. The traditional ploughing or rotary tillage, which is widely used at present, causes the surface to be exposed, which accelerates the depletion of soil and reduces the quality of cultivated land and the ability of soil to continuously supply fertilizer [7]. Zhang and other studies have shown that Deep pine could promote the growth of maize in the early stage of North China, and no-tillage promotes the growth in the later stage, while Deep pine could promote the increase of wheat yield [9]. Zhang simulated the global warming potential (GWP) of CO₂, CH₄ and N₂O emissions in the winter wheat/summer maize rotation soil in North China. The results showed that the GWP values under different tillage methods were tillage > rotary tillage > No-till [10]. The effects of farming methods on greenhouse gas emissions and winter wheat yield may be a more suitable rotational tillage mode in short-term rotation. The rotary tillage system is not conducive to control greenhouse gas emissions, but it is necessary to strengthen the long-term effects on different rotation methods [11].

Although domestic and foreign scholars have conducted a lot of research on N₂O emissions from farmland in North China, most of them are single test resulting in specific regions and lack systematic. Therefore, this paper comprehensively analyzed the effects of different tillage methods on soil N₂O and crop yields in wheat and corn fields in North China by consulting a large number of published literatures, trying to clarify the rational N₂O emission reduction and crop yield increase mode of the grain field system. Provide scientific basis for agricultural safety production in North China.

2. Materials and Methods

In this paper, winter wheat and summer maize were used as research objects to study the effects of different tillage methods on their N₂O emissions and yields. The recent and published domestic and international journals and doctoral dissertations were reviewed and comprehensively analyzed. The same indicators in different literatures were converted into uniform units, and the calculation of N₂O emission reduction and crop yield increase were based on no-till treatment. The calculation formula for each indicator is:

\[
\text{N}_2\text{O emission increase rate (\%) = \frac{(nitrogen treatment N}_2\text{O emissions - no nitrogen treatment N}_2\text{O emissions)} / \text{no nitrogen treatment N}_2\text{O emissions} \times 100}
\]

\[
\text{Crop yield increase (\%) = \frac{(nitrogen treatment crop yield - no nitrogen treatment crop yield)} / \text{no nitrogen treatment crop yield} \times 100}
\]

\[
\text{N}_2\text{O emissions per unit of nitrogen fertilizer (g kg}^{-1} = \frac{\text{N}_2\text{O emissions from nitrogen treatment}} / \text{pure nitrogen application} \times 1000}
\]

\[
\text{Unit production N}_2\text{O emissions (mg kg}^{-1} = \frac{\text{N}_2\text{O emissions}} / \text{crop yield} \times 10^6
\]

3. Results and analysis

3.1. Effects of different tillage methods on N₂O emission and yield in wheat fields

The research on the N₂O emission from farmland mainly focused on straw returning and conservation tillage. The author collected different farming methods under the straw returning to the field to avoid no tillage. Compared with no tillage, most other farming practices increased N₂O emissions from wheat fields, ranging from -2.3% to 640%, and wheat yields from -6.6% to 26.7% (Table 1). Conventional tillage increased soil N₂O emissions by 2.3% to 30.8%, and crops did not achieve significant yield increases when emissions were greatest. Traditional farming not only increases N₂O emissions compared to no-tillage, but also leads to crop yield reduction. Under rotary tillage, N₂O increased by -2.3% to 47.4%, wheat yield increased by -2.5% to 22.9%, crop yield increased by 4.8%, and crop yield decreased by 19.5% to 35.4%, indicating that rotary tillage is not conducive to N₂O emission reduction and crop yield increase in farmland. No-tillage or rotary tillage after deep pine and deep pine increased N₂O emissions, and no-tillage reduced yield by 6.6% after deep pine. The N₂O emission reduction and yield increase by raking were not obvious, straw removal, straw deep application or straw surface increased yield by 6.7%–15.5%, but N₂O emission increased by 640%. Therefore, no-tillage is the current farming measure that both reduces N₂O emission and stabilizes wheat yield.
Table 1. Effects of different tillage methods on soil N$_2$O emission and yield of wheat

| Literature basis | Treatments                   | Total N$_2$O emissions /kg hm$^{-2}$ | N$_2$O increase rate /% | Crop yield /kg hm$^{-2}$ | Rate of wheat growth /% |
|------------------|------------------------------|--------------------------------------|-------------------------|--------------------------|-------------------------|
| Zhang [12]       | no tillage                   | 0.65                                 | 0                       | 7671                     | 0                       |
|                  | conventional tillage         | 0.85                                 | 30.8                    | 7695                     | 0.31                    |
|                  | rotary tillage               | 0.88                                 | 35.4                    | 7481                     | -2.5                    |
|                  | no tillage                   | 1.33                                 | 0                       | 6844                     | 0                       |
| Hojatollah [13]  | no tillage after deep pine   | 2.45                                 | 84.2                    | 6392                     | -6.6                    |
|                  | rotary tillage after deep pine | 3.06                             | 130.1                   | 7381                     | 7.8                     |
|                  | no tillage                   | 1.96                                 | 47.4                    | 7172                     | 4.8                     |
|                  | conventional tillage         | 1.71                                 | 0                       | 3915                     | 0                       |
| Tian [14]        | deep pine                    | 1.77                                 | 3.5                     | 4189                     | 7.0                     |
|                  | rake tillage                 | 1.76                                 | 2.9                     | 4688                     | 19.7                    |
|                  | rotary tillage               | 1.67                                 | -2.3                    | 4813                     | 22.9                    |
|                  | no tillage                   | 0.05                                 | 0                       | 5543                     | 0                       |
| Wan [15]         | straw removal                | 0.32                                 | 540                     | 5912                     | 6.7                     |
|                  | straw surface                | 0.10                                 | 100                     | 6212                     | 12.1                    |
|                  | straw deep                   | 0.37                                 | 640                     | 6404                     | 15.5                    |
|                  | no tillage                   | 1.33                                 | 0                       | 6096                     | 0                       |
| Zhao [16]        | conventional tillage         | 1.48                                 | 11.3                    | 7088                     | 16.3                    |
|                  | deep pine                    | 1.42                                 | 6.8                     | 7726                     | 26.7                    |
|                  | rake tillage                 | 1.64                                 | 23.3                    | 7286                     | 19.5                    |
|                  | rotary tillage               | 1.59                                 | 19.5                    | 5945                     | -2.5                    |

3.2. Effects of tillage methods on soil N$_2$O emissions and maize yield

Compared with no-tillage, the conventional farming methods of each test reduced N$_2$O by 5.7% to 17.4%, but increased production by less than 1% (Table 2). Deep pine can reduce N2O by 3.9% to 14.6% and corn yield by 9.7%, raking could reduce N$_2$O 2.2%~11.9% and corn yield 1.5%, it indicated that all three farming methods are conducive to stable yield reduction in corn fields. Under the rotary tillage mode, the N$_2$O increase rate is -6.9%~5.8%, and the corn yield is reduced by 1.3%, indicated that rotary tillage is not beneficial to corn field yield increase and emission reduction. No tillage after deep pine, the no tillage increased N$_2$O by 42.6% and the crop yield was reduced by 12.2%; the tillage increased N$_2$O by 71.1%. Therefore, it is recommended that the corn field use conventional tillage, deep pine or rake tillage.

Table 2. Effects of different tillage methods on soil N$_2$O emission and yield of maize

| Literature basis | Treatments                   | Total N$_2$O emissions /kg hm$^{-2}$ | N$_2$O increase rate /% | Crop yield /kg hm$^{-2}$ | Rate of maize growth /% |
|------------------|------------------------------|--------------------------------------|-------------------------|--------------------------|-------------------------|
| Hojatollah [13]  | no tillage                   | 2.70                                 | 0                       | 9683                     | 0                       |
|                  | no tillage after deep pine   | 3.85                                 | 42.6                    | 8499                     | -12.2                   |
|                  | no tillage                   | 2.29                                 | 0                       | —                        | —                       |
|                  | conventional tillage         | 2.16                                 | -5.7                    | —                        | —                       |
| Tian [14]        | deep pine                    | 2.20                                 | -3.9                    | —                        | —                       |
|                  | rake tillage                 | 2.24                                 | -2.2                    | —                        | —                       |
|                  | rotary tillage               | 2.32                                 | 1.3                     | —                        | —                       |
| Zhao [16]        | no tillage                   | 5.63                                 | 0                       | 8581                     | 0                       |
### 4. Conclusions and discussion

Straw returning has been applied to North China in large scale, and the research on the impact of farming methods on N\textsubscript{2}O emissions from farmland is still controversial. This paper showed that on the basis of straw returning to the field, no potential for no tillage and yield reduction was high, but there was no significant difference between the cornfield farming practices. Zhang reported that N\textsubscript{2}O emissions from wheat fields under no-tillage and straw returning were lower than traditional tillage, and conservation tillage reduced soil N\textsubscript{2}O emissions [12]. Flechard pointed out that traditional farming had higher N\textsubscript{2}O emissions than no till, which was related to soil temperature, soil moisture and soil properties [18]. No tillage increased N\textsubscript{2}O emissions from soil with poor ventilation conditions had little effect on well ventilated soil [19]. Related to the application of nitrogen fertilizer, the nitrogen fertilizer input in the maize season was generally higher than that in the wheat season, which results in a larger nitrogen fertilizer input than the tillage method had a greater effect on N\textsubscript{2}O emissions [20-21]. Straw mulching can also interact with farming methods [22], but the mechanism of N\textsubscript{2}O emission was complex and the results were uncertain.

Therefore, taking both N\textsubscript{2}O emission reduction and crop yield in grain fields into account, the recommended management techniques for wheat and maize season are: no till measures could reduced emissions in the wheat season; conventional tillage, deep pine or rake tillage on the basis of straw returning in the maize season, could stabilize production and reduce emissions.

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