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Organic Fertilizer Application Effects on Soil Agglomeration Stability and Organic Carbon and Total Nitrogen Distribution: A Meta-Analysis

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Abstract. The application of organic fertilizers is a standard measure of circular agriculture, which can purify the environment, ensure food safety and strengthen the sustainable use of soil. The purpose of this study was to evaluate the effects of organic fertilizers on the stability of soil aggregates and soil fertility using a meta-analysis. A total of 169 case-controlled studies from 45 papers were included through screening, and Wordy sentences 169 soil data from the organic fertilizer group and 169 soil data from the control group (CK) were collected. The stability of meta-analysis results after combining effect sizes was assessed by sensitivity analysis, and the publication bias was evaluated by funnel plot. Meta-analysis results showed that the application of organic fertilizer significantly affected the mean weight diameter (MWD) ($P<0.05$), increased the organic carbon (SOC) content of the soil ($P<0.05$) .and significantly increased the total nitrogen (STN) content of the earth ($P<0.05$). Funnel plot analysis showed that there was only a small amount of publication bias in the study .and sensitivity research showed that the analysis was stable and reliable. In conclusion, the application of organic fertilizer can significantly affect the stability of soil aggregates and has a potentially positive effect on improving soil fertility. This meta-analysis provides a scientific basis for the rational utilization of organic fertilizers and soil structure optimization in China.

Keywords: Organic fertilizer; Mean weight diameter; Soil organic carbon; Soil total nitrogen.

1. Introduction

Chemical fertilizer is widely used in China's agricultural production, while organic fertilizer is rarely used, leading to an increasing dependence on chemical fertilizer in farmland. However, long-term chemical fertilizer application fertilizer has caused severe effects on soil in China, such as decreased soil fertility, soil hardening. and reduced productivity[1]. Excessive fertilizer application can also lead to surface eutrophication and shallow water pollution. Organic fertilizer can provide many nutrients, increase the content of soil organic matter, and enhance the stability of soil aggregates[2].Therefore, the application of organic fertilizer is one of the hot spots in the world.The quality of soil structure is not only related to the size, character .and fertility characteristics of soil structure but also related to the stability of systems. The strength of soil structure stability can be divided into water stability, force stability ,and biological stability. Different soil structures have extra peace. According to the strength of soil structure, soil aggregates can be divided into water-stable aggregates, force stable aggregates ,and natural stable biological ggregates.

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Soil aggregates refer to the structural units in soil with different sizes and shapes, porosity, mechanical stability ,and water stability. The strength of soil aggregates is a crucial index of soil structure, which result from the interaction of soil environment, soil management practice ,and land use types. Generally, the higher the content, the better the structure and properties of the soil [3]. The more large aggregates in the earth, the stronger the ability to retain organic matter. The results showed that applying different organic fertilizers could increase the content of organic matter in the soil, promote the formation of water-stable aggregates with large particle sizes, improve soil nutrients, and enhance the water stability of aggregates. Soil organic matter increased ,and soil aggregates became more stable. Therefore, the study of soil aggregates has far-reaching significance and influence on soil research[4]. The results show that the CO2 released from crushed macroaggregates is 34%~61% more than that from intact macroaggregates[5]. The stability of soil agglomerates are generally assessed by the mean weight diameter (WMD) and the geometric mean diameter (GMD).The higher the percentage of large agglomerates, the larger the MWD and GMD values; the more stable the agglomerates[6]. Therefore, the application applying different organic fertilizers can increase the water stability and mechanical stability of soil aggregates, increase the content of soil organic matter and improve soil structure.

The aggregate is called the soil nutrient pool, and the soil aggregate is the basic unit of soil structure. The properties and fertility of soil are determined by the quantity and quality of soil aggregates[7]. The mechanical stability of the earth determines the physical properties of the earth, and the water stability of the earth determines the water retention and erosion resistance of the earth. Soil mechanical stability and water stability are two crucial factors in studying the properties of soil aggregates. Organic matter is the basis of soil properties. Therefore, studying the effects of different organic fertilizers on soil aggregates and organic matter is the key to understanding soil properties. There have been many studies on the impact of other organic fertilizers on soil aggregates such as aquic soil, black soil, paddy soil ,and brown soil. It is believed that organic fertilizers are beneficial to the accumulation of organic carbon in soil aggregates and improve the stability of soil aggregates. However, some studies believe that organic fertilizer is not conducive to the collection of organic carbon and the improvement of the stability of aggregates[8]. In this study, a meta-analysis was used to analyze 45 kinds of literature and comprehensively evaluated whether applying organic fertilizer was beneficial to improving soil aggregate stability. This study can provide a scientific basis for the development of organic agricultural production and the improvement of soil quality in China in the future.

2. Materials and Methods

2.1 Literature Retrieval

Keywords such as “fertilization application”, “Mean weight diameter”, “Soil agglomerates”, “soil organic carbon”, and “soil total nitrogen” were entered into Chinese Databases such as CNKI, Wanfang database, and China sience citation database (CSCD), meanwhile entered into English databases such as Pubmed, Web of Science and Science direct. The search time range is from 2001 to 2019.

2.2 Literature Screening

The literature was screened according to the following conditions: 1) The research contents include the Effect of organic fertilizer application on the stability of soil aggregates. 2) The results included soil mean weight diameter (MWD), organic carbon (SOC) ,and total nitrogen (STN). 3) The literature shall be in Chinese or English. All the retrieved literature materials were screened and extracted independently by two participants and then reviewed. According to the literature retrieval rules,141478 literature were retrieved, among which 556 kinds of literature were excluded from repeated literature, conference papers, conference abstracts, unpublished papers, non-core journal papers ,and non-SCI papers. Through reading the titles and abstracts of the literature, 424 articles on

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organic fertilizer free treatment and reviews were excluded. After further reading the complete text, 389 quasi-literatures that did not meet the inclusion criteria, such as uncontrolled studies and unmeasured outcome indicators, were banned, and 45 kinds of literature were finally included[9-53].

2.3 Data Extraction and Characterization

Among the 45 included literature, 169 control studies were extracted according to the experimental design, The following data were extracted respectively: Literature title, publication time, survey area, soil type, fertilization duration, screening method, soil layer thickness, total soil amount, and other information, as well as test data and standard deviation (mean weight diameter, soil organic carbon, soil total nitrogen). Different studies with the same author in the same year were distinguished by (1) (2) (3) (4). A total of 45 studies were included in this meta-analysis, including 23 MWD studies, 43 SOC studies, and 25 STN studies, including 169 case-control examinations. 169 soil data from the organic fertilizer group and the control group (CK) were collected, and all the included studies included the organic fertilizer and controlled trials.

2.4 Statistical Methods

Meta package of R language was used for Meta-analysis of the extracted data. 1) Effect scale selection: since the outcome indicators of the included literature were all continuous variables, the standardized mean difference (SMD) was selected as the effect length scale and calculated the 95% confidence interval. 2) Meta-analysis: inverse Variance method combine the effects. 3) Heterogeneity test: Q test and I2 value were used for inter-study heterogeneity analysis. When I2 < 50%, the heterogeneity between studies was considered below, and the effect sizes were pooled using a fixed model; When I2 > was 50%, it was considered that there was high heterogeneity among studies, then Random Model was used to combine effect sizes. 4) Published partially: funnel plot analysis was used to test whether there was publication bias. When P<0.05, the difference was considered to be significant. If there was publication bias, the rank method was used to correct it. 5) Sensitivity analysis: each study was excluded in order of 101 to evaluate its influence on combined effect size and heterogeneity, and to evaluate the stability of the results.

3. Results

3.1 Meta-analysis of Organic Fertilizer Application on Soil MWD

The results showed heterogeneity in the quantity of MWD after long-term application of organic fertilization among studies(P<0.001, I2=99.4%), therefore, the random-effects model was used to combine the effect sizes. The result (Figure 1) shows that the combined effect size is to the right of the invalid line and does not intersect with the weak line, which indicates long-term application of organic fertilizer could significantly increase the mean weight diameter(MWD)(P<0.001).

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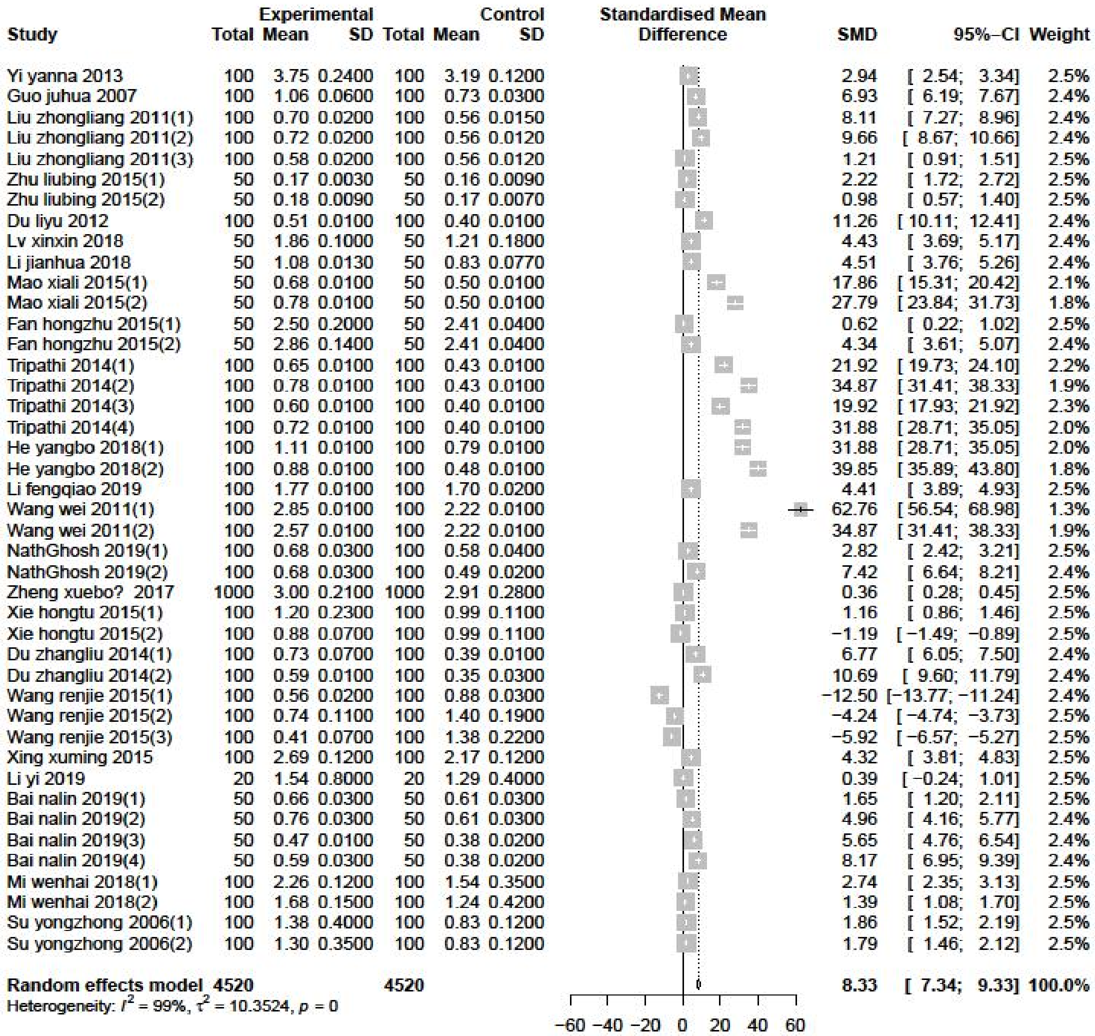

Fig.1 Forest plot for meta-analysis of organic fertilizer application on soil MWD

3.2 Meta-analysis of Organic Fertilizer Application on SOC

The results showed heterogeneity among studies on the change of SOC after long-term application of organic fertilizer (P<0.001, I2=99.5%), therefore, the random-effects model was used to combine the effect sizes. The result (Figure 2) shows that the combined effect size is to the right of the invalid line and does not intersect with the weak line, which indicates long-term application of organic fertilizer could significantly increase soil total organic carbon(SOC)(P<0.001).

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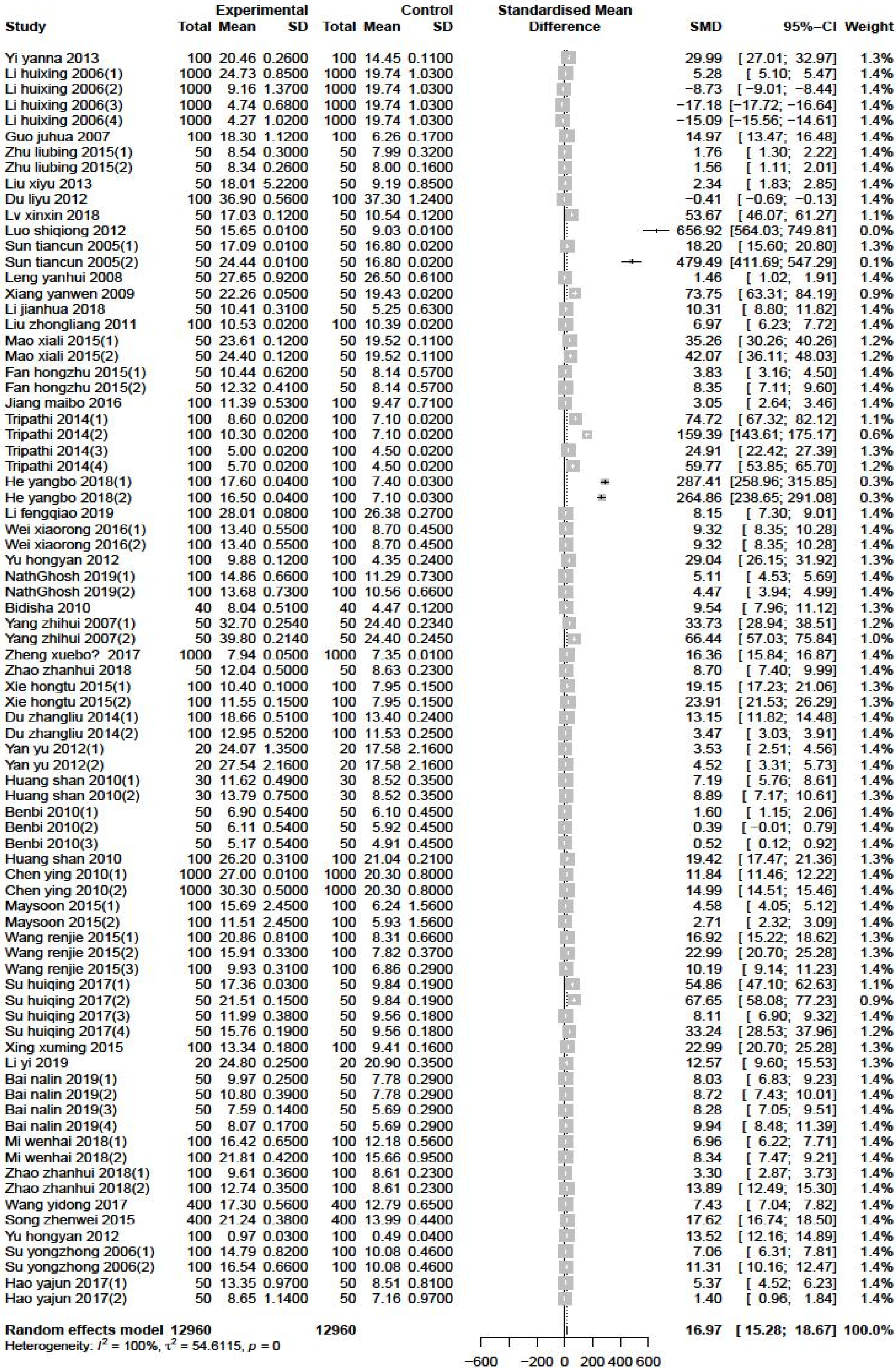

Fig.2 Forest plot for meta-analysis of organic fertilizer application on SOC

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3.3 Meta-analysis of Organic Fertilizer Application on STN

The results showed that heterogeneity in the number of outcome index STN after long-term application of organic fertilizer (P<0.001, I2=99.6%), therefore, the random-effects model was used to combine the effect sizes. The result (Figure 3) shows that the combined effect size is to the right of the invalid line and does not intersect with the weak line, which indicates long-term application of organic fertilizer could significantly increase total soil nitrogen(STN)(P<0.001).

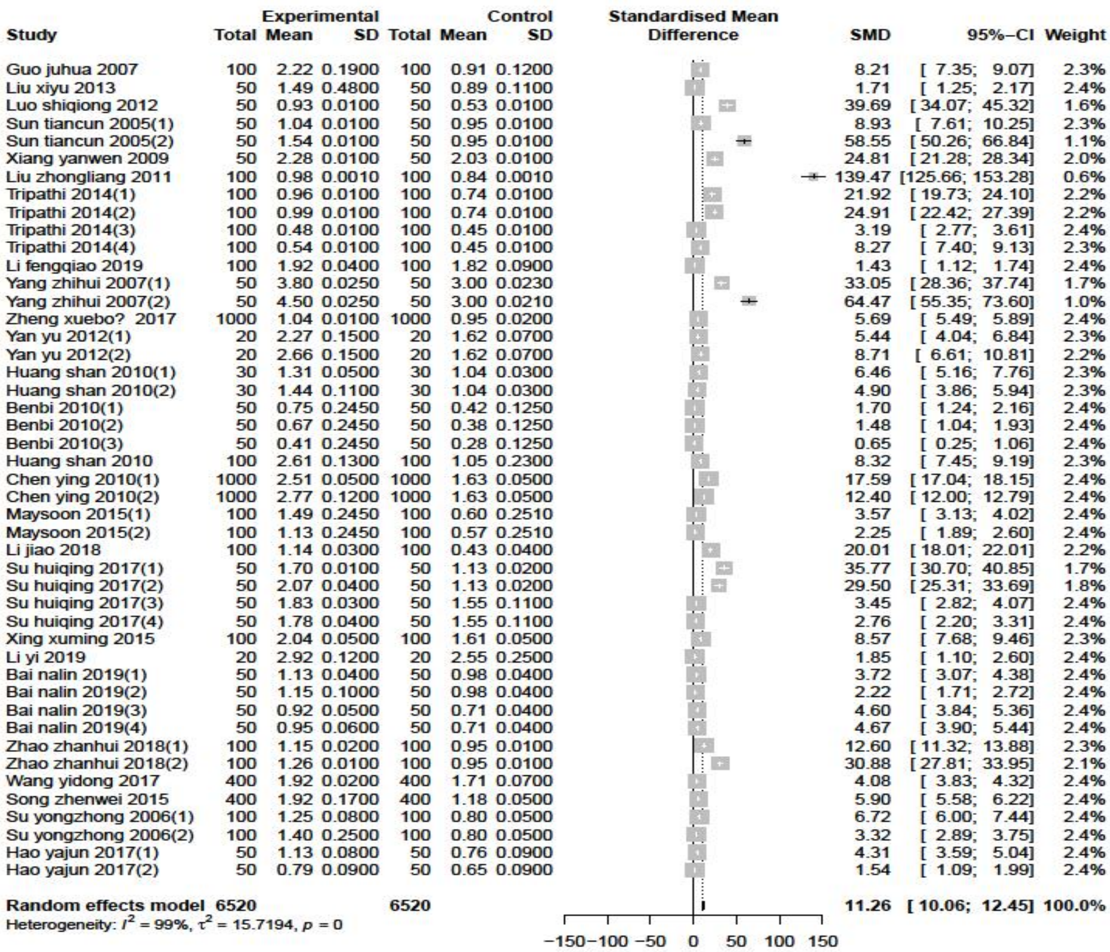

Fig.3 Forest plot for meta-analysis of organic fertilizer application on STN

3.4 Sensitivity Analysis

The application of organic fertilizer significantly affected soil aggregates MWD, SOC ,and STN (Table 1). The results of this meta-analysis were highly heterogeneous (I2>50%, P<0.01), and the stability and reliability of the analysis results needed to be evaluated. The results of the sensitivity analysis showed that after all the included studies were successively excluded, the combined effect values of the remaining studies were on both sides of the invalid line and did not intersect, which further demonstrated the accuracy of the results of this meta-analysis.

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Table 1. Results of meta-analysis on the effect of organic fertilizer application on soil agglomerates

indicators	No. of included literature	No. of experimental controls	SMD(95%CI)		Heterogeneity test	
			Effect size	P-value	I2 /%	P-value
MWD	23	43	8.334[7.34-9.33]	<0.0001	99.50%	<0.01
SOC	43	80	16.974[15.28-18.67]	<0.0001	99.80%	<0.01
STN	25	46	11.256[10.06-12.45]	<0.0001	99.50%	<0.01

3.5 Publication Bias Analysis

The results of the funnel plot analysis are show in Figure 4. Figure 4b and.Figure 4c show that most of the studies about SOC and STN are distributed in the upper part of the funnel plot and concentrated in the middle, but there are a few studies distributed outside the funnel plot. This indicates that the sample size of the study is significant and representative and the experiment has high precision and accurate data. Figure 4a shows that most of the studies about MWD focused on the middle and upper part of the funnel plot.Still, the symmetry was poor, and some of the studies were distributed in the lower leg or outside of the funnel plot, indicating a small amount of publication bias. The trim and filled model was used for correction, and the corrected analysis results were shown in Table 2. Post-correction results showed the Effect of organic fertilizer application on soil MWD was still statistically significant (P=0.029). This adds up to points, indicating the reliability of the previous meta-results. Similarly, for the SOC index and STN index, corrected results show that the P-value of SOC (0.001) and the p-value of STN (<0.0001) reached statistical significance. The above results fully re-verified the reliability of the Meta-analysis results.

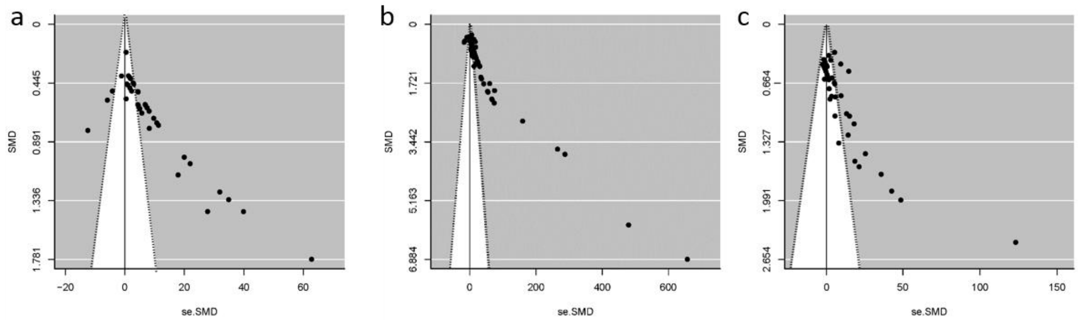

Fig.4 Funnel plots of 95% confidence intervals for the effect of organic fertiliser application on mean weight diameter, total organic carbon and total nitrogen

Table 2. Summary of results after meta-analysis correction

indicators	No. of experimental controls post-correction results	SMD(95%CI)		Heterogeneity test	
		Effect size	P-value	I2 /%	P-value
MWD	60	1.164[0.11-2.21]	0.029	99.60%	<0.01
SOC	116	2.850[1.19-4.51]	0.001	99.80%	<0.01
STN	60	4.471[3.17-5.78]	<0.0001	99.60%	<0.01

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4. Discussion

4.1 Effect of Organic Fertilizer Application on Soil Aggregates MWD

The stability of soil aggregates was generally evaluated by the mean weight diameter (MWD) value[6]. In recent years, there have been many studies on the effects of organic fertilizer on soil aggregates such as aquic soil, black soil, paddy soil,and brown soil. It concluded that organic fertilizer was beneficial to the accumulation of organic carbon in soil aggregates and improved the stability of soil aggregates. Huang et al. [54] studied the application content and characteristic values of soil aggregates with different particle sizes after 23 years of continuous fertilization in red paddy soil by dry screening method. Compared with CK, the results showed that the application of organic fertilizers significantly increased the mean weight diameter (MWD) of paddy soil aggregates, and there was a significant positive correlation between the MWD of paddy soil aggregates and annual rice yield. Therefore, the MWD of soil aggregates can objectively reflect the state of soil fertility. The meta-analysis results included 43 control studies in this paper showed that long-term application of organic fertilizer could significantly increase the MWD index of soil aggregates, similar to the previous conclusion. Despite the heterogeneity of the MWD study, we also conducted correction analyses, and the results also confirmed the reliability of the results of the meta-analysis. In addition, sensitivity analysis showed that the size of the pooled Effect remained statistically significant for every study that were excluded studies. In summary, this meta-analysis result is stable and reliable ,and the Long-term application of organic fertilizer can significantly improve MWD. More importantly, the related study reported a positive correlation between the size of MWD and soil stability was existed[55]. Conclusively, it was indicated that organic fertilizers could effectively improve the strength of soil aggregates after long-term application.

4.2 Effect of Organic Fertilizer.Application on SOC

The application of organic fertilizer was a necessary measure to increase soil organic carbon (SOC) content, promote the formation of soil aggregates and improve soil structure. Soil organic carbon (SOC) content and its dynamic balance were not only an important indicator of soil health, but also affected soil structure formation, stability ,and soil fertility to a great extent. Li et al. [56]studied the response of total organic carbon, aggregate composition ,and organic carbon content of aggregates with different particle sizes in wheat and rotation system in the 32-year-old lime coniferous black soil to different fertilization patterns in the long-term stage. It was found that long-term application of organic fertilizer could increase the total organic carbon content, the number of medium aggregates,and the content of organic carbon, which was beneficial to improving soil physical properties and enhancing soil fertility. Wei et al. [57] studied the effects of different types of organic fertilizers including heap manure, chicken manure, cow manure,and pig manure,on the composition of organic carbon and humus in the soil. The results showed that organic fertilizer combined with organic fertilizer increased the contents of organic carbon and humus carbon in soil aggregates.Still, the effects of different organic fertilizers were other. Han et al. [58] showed in their study on the brown soil that the single application of NPK had little Effect on the soil's organic carbon content . In contrast, the combined application of organic matter and organic fertilizer could significantly increase the organic carbon content. The meta-analysis results included 80 control studies in this paper showed that long-term application of organic fertilizer could dramatically increase the SOC index in soil aggregates, similar to the previous conclusion. It has been reported that soil organic carbon content and MWD water stability showed positive correlations[55].Therefore, it was speculated that SOC content in the soil also played a positive role in the strength of soil aggregates.

4.3 Effect of Organic Fertilizer Application on STN

Soil total nitrogen, as the most essential nutrient element for plant growth, was also an important index to measure soil quality and soil productivity, mainly since it was considered to be playing a

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vital role in the process of crop growth. As the foundation of ground, aggregates not only affect the physical properties of soil, but also affect the accumulation and release of nitrogen in soil due to the different sizes of aggregates' adsorption and protection ability[59]. Therefore, the study of nitrogen content and distribution in soil aggregates, was of great significance for regulating soil fertility and increasing soil nitrogen storage. Most studies believe that long-term application of organic fertilizer can significantly increase soil total nitrogen content. Sun et al. [28] realted studies have reported that the long-term fertilization significantly improve the soil entire nitrogen content in the surface layer of brown soil. The meta-analysis results included 46 control studies in this paper showed that long-term application of organic fertilizer could significantly increase the STN index of soil aggregates, similar to the previous conclusion.

4.4 Limitations

There were some limitations in this study. First of all, the overall quality of the literature included in this paper was high,but still had incomplete data and a small number of odd publications, which may have a particular impact on the results of the Meta-analysis. In addition, there were differences in environmental conditions such as fertilization duration, survey area, annual rainfall, average annual temperature, altitude, climate type, soil type, soil thickness, soil screening method,and other experimental manipulation factors among the included studies. Longer fertilization duration may easily lead to changes in relevant outcome indicators. Thus, the stability of soil aggregates can be affected unpredictably. Therefore, unclear environmental conditions may be the underlying heterogeneity factor. Second, Although many studies have pointed out the close relationship between soil organic matter and soil quality and crop yield, other studies have shown that the relationship between soil quality indicators such as soil organic carbon (SOC) and soil function does not always offer a linear relationship. Third, research shows that the particle size of aggregate distribution differences of organic carbon, total nitrogen, this analysis into the experiment according to the number for the whole soil reunion total content, not ending index under various particle size data, know so for or fertilization treatment on aggregate stability and total carbon, total nitrogen affects the mechanism of action is not enough in-depth enough, lacks systematicness and comprehensiveness.Therefore, although this experiment obtained the relevant prediction conclusions, application of organic fertilizer on soil organic carbon, and total nitrogen trend, the study of soil stability can not make an accurate prediction.

5. Conclusions

First, the Meta-analysis confirmed that the application of organic fertilizer could significantly improve the MWD of soil aggregates, thus improving the stability of soil aggregates. In addition, the contents of total organic carbon (SOC) and total nitrogen (STN) in soil were significantly increased by applying organic fertilizer. Second, applying organic fertilizers as a conventional farming strategy has practical significance in improving soil fertility and structure.

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