agronomy

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Study of the Effects of Different Agronomic Practices on Inorganic Carbon in the Plough Layer of Dryland Field: A Meta-Analysis

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Citation: Niu, X.; Yu, Y.; Dong, J.; Ma, Y.; Wang, L.; Dai, W.; Luan, Y. Study of the Effects of Different Agronomic Practices on Inorganic Carbon in the Plough Layer of Dryland Field: A Meta-Analysis. *Agronomy* **2023**, *13*, 736. https://doi.org/10.3390/agronomy13030736

Academic Editors: Kazem Zamanian and Xiaoning Zhao

Received: 20 January 2023
Revised: 24 February 2023
Accepted: 26 February 2023
Published: 28 February 2023

Abstract: Soil inorganic carbon (SIC) is an essential component of the soil carbon pool and plays a vital role in the global carbon cycle and climate change. However, few studies have examined the effects of different agronomic practices on the SIC content. This paper aims to study the effects of different agronomic practices on the SIC content in the 0- to 40-cm soil layer of dryland fields; the innovations are intended to explore the relative importance and synergistic effects of different agronomic practices on the SIC content of the plough layer of dryland fields. We screened out 136 peer-reviewed articles worldwide from 1990–2022, with a total of 2612 valid data pairs, using meta-analysis to assess the effects of different agronomic practices on the SIC content of the plough layer of dryland fields. Compared to conventional tillage (CT), both no-tillage (NT) and plastic film mulching (PM) were able to increase the SIC content in the 0- to 40-cm soil layer of dryland fields. NT increased the SIC content by 15.07 ± 3.48%, while PM gradually increased SIC accumulation as the soil layer deepened, with the greatest increase in SIC content in the 30- to 40-cm soil layer at 11.61 ± 5.89%. When organic manure application (M) and straw return mulching (SM) were applied, the SIC content in the 0- to 40-cm soil layer of dryland fields showed a non-significant reduction trend, with the largest changes in SIC content in the 0- to 10-cm soil layer, at 5.23 ± 2% and 4.69 ± 3.53% reductions, respectively. No-tillage straw return (NTS) significantly increased the SIC content in the 0- to 40-cm soil layer of dryland fields by 77.34 ± 5.6%, which was significantly higher than the independent effects of NT and SM, showing a more substantial synergistic effect. Different agronomic practices have different effects on the SIC content of dryland fields in the 0- to 40-cm soil layer, with NTS > NT > PM > SM > M. Among practices, NTS, NT and PM can increase the SIC content of the plough layer of dryland fields; in particular, NTS can increase the SIC content of 0- to 40-cm in dryland fields to the greatest extent through a synergistic effect. At the same time, SM and M showed an insignificant reduction effect.

Keywords: dryland field; soil inorganic carbon; agronomic practices; meta-analysis; synergistic effects

1. Introduction

Agricultural soil carbon (C) is an essential component of the global carbon pool, which is most affected by external conditions, such as human activities [1], and it consists of soil organic carbon (SOC) and soil inorganic carbon (SIC) [2]. SIC includes carbonate ($CaCO_3$) precipitated in soil, HCO−3 in soil solution and CO_2 in soil air, among which $CaCO_3$ is predominant, mainly in the form of nodules and mycelium in the soil profile [3]. Soil carbonates are divided into lithogenic carbonates (LCs) and pedogenic carbonates (PCs), with LCs mainly derived from soil-forming parent rocks, while PCs are formed through the chemical reaction of CO_2 in soil solution and Ca^{2+}, Mg^{2+} recrystallization, or dissolution and re-precipitation of LCs, newly forming PCs [4,5]. The solid-phase carbonate form of SIC is mainly $CaCO_3$ [4,6]. Ca is the most essential cementing agent for maintaining soil structure, significantly improving soil water-holding capacity and soil's potential for rapid absorption and retention of large amounts of soil water, contributing to increased drought resistance in farmland systems [7–12]. It was found that soil with high SIC content in arid areas can reach an average water content of 0.33 m^3m^{-3} to 0.36 m^3m^{-3} and has the potential to absorb and retain large amounts of soil water rapidly, enhancing plant resistance to drought [8,11].

Soil inorganic carbon (SIC) is the primary form of soil carbon in arid regions [13]. Studies have shown that the storage of SIC in arid and semi-arid areas is about 2–10 times greater than that of SOC [14], suggesting that the carbon cycle in this region may be strongly influenced by the dynamics of SIC [15,16]. SIC undergoes rapid changes that may have important implications for the dynamics of total soil carbon fluxes [17]. For example, about 13–38% of CO_2 released from soil comes from SIC decomposition [18–20], suggesting that SIC contributes significantly to total soil carbon emissions. Some studies have found abiotic CO_2 uptake in arid regions, implying that SIC has the potential to be a carbon sink in modern carbon cycling processes [21]. Therefore, elucidating the effects of different agronomic practices on the SIC content of dryland fields is of great significance for carbon sequestration and emission reduction.

Human agronomic practices substantially affect the SIC pool in agriculture [22], and it is important for dryland agricultural production to explore the regulation of SIC content through improved agronomic practices and thus improve soil moisture conditions. No-tillage (NT) [23], no-tillage straw return (NTS) [24], organic manure application (M) [25,26], plastic film mulching (PM) [27] and straw return mulching (SM) [28] have been found to affect the transformation pathways of SOC and SIC in topsoil [29], the leaching intensity of precipitation [30] and soil pH [31] to alter the SIC content of the plough layer. For example, Walmsley [24] found that reducing farm tillage reduced aeration in the topsoil, which not only resulted in the slower dissolution of SIC but also reduced leaching losses of SIC from the plough layer. Moreno [23] found that NT and NTS conservation tillage significantly increased the surface SIC content compared to conventional tillage, with 15% and 48% increases in the 0- to 25-cm soil layer, respectively. However, Dong [32] found no significant effect of NT on SIC through long-term trials. Zeng [33] found that the SIC contents were reduced by 7.41% and 5.27% for organic manure and green manure applications, respectively, compared to no manure application in a long-term location experiment. However, Bughio [25] found that the SIC content in the 0 to 20-cm soil layer of dryland fields was higher than in the control group after applying organic manure. Li [34] found that there were significant differences in the effects of different land cover methods on the SIC content of the 0 to 40-cm soil layer through long-term location experiments, with PM significantly increasing SIC content by 2.4–6.0 Mg C ha^{-1} but SM reducing SIC content by 0.5–2.5 Mg C ha^{-1}. In contrast, Li [28] found that PM had no effect on the SIC content of the 0- to 30-cm soil layer in dryland fields, and Gao [35] found that SM promoted the formation of pedogenic inorganic carbon and facilitated the accumulation of inorganic carbon in dryland field. So far, researchers have performed studies related to the response of SIC content to different agronomic practices in dryland fields [36,37], but due to different soil properties and hydrothermal conditions in different regions, the findings have varied, while there is also a lack of studies of the synergistic effects of different agronomic practices on SIC content in dryland field, affecting a deeper understanding and knowledge of the effects of different agronomic practices on the SIC content of dryland farmland.

This study aims to compare the effects of different agronomic practices on the SIC content of dryland fields in the 0 to 40-cm plough layer, and it analyses the relative importance and synergistic effects of different agronomic practices on the SIC content of the plough layer of dryland fields. To meet this objective, we use meta-analysis, an analytical tool that enables the integration and comparison of multiple studies and can lead to relatively general conclusions on a large scale [38,39]. Therefore, this paper uses meta-analysis to compare the effects of different agronomic practices on the SIC content of dryland fields in the 0 to 40-cm plough layer by collecting, screening and integrating published literature data; the innovation lies in analyzing the changes in the main physical and chemical properties of the soil after treatment with different agronomic practices, exploring the intrinsic causes of the changes in SIC content and analyzing the synergistic effects between different agronomic practices and SIC content. The aims are to clarify the intensity of the impact of different agronomic practices on the SIC content of the plough layer of dryland fields, to enhance the drought resistance of dryland field crops and improve crop yields, and to expand the importance of SIC for carbon sequestration and emissions reduction.

2. Materials and methods

2.1. Data Extraction and Collection

First, we searched the Web of Science and the China Knowledge Resource Integrated Database (CNKI) (the original pool) based on keywords to obtain relevant articles and removed duplicates. Then, the articles that did not meet the requirements were excluded by titles and abstracts, and the filtered articles were evaluated by reading the full texts and removing those that did not meet the inclusion criteria. Finally, 136 articles that met the criteria were derived, and the data from the articles were extracted using Microsoft Excel 2010 software (Redmond, U.S.) and GetData Graph Digitizer software (Shanghai, CHN). All data were obtained from the Web of Science and the China Knowledge Resource Integrated Database (CNKI), and peer-reviewed articles were searched from 1990 to 2022. The main keywords used in the peer-reviewed article search were “dryland field”, “conservation tillage”, “no-tillage”, “no-tillage straw return”, “organic manure application”, “plastic film mulching”, “straw return mulching”, “inorganic carbon”, "carbonate”, and “soil physicochemical properties”. To improve the representativeness and accuracy of the data, the following criteria were included in the peer-reviewed articles: (1) the test area was dryland field (large field experiment); (2) the soil sampling depth of the test was 40 cm; (3) the agronomic practices of the test included control (CT), no-tillage (NT), no-tillage straw return (NTS), organic manure application (M), plastic film mulching (PM) and straw return mulching (SM) under the same conditions; (4) the control group (CT) under different agronomic practices was conventional tillage with the same conditions; (5) data such as repeat numbers, mean values and standard deviations (or standard errors) from the peer-reviewed article were clearly recorded. Through screening, a total of 136 literature articles and 2612 data pairs were obtained that met the criteria. The SIC database for dryland fields was created using Microsoft Excel 2010 software (Redmond, U.S.), including the soil depth, repeat numbers and mean values, and standard deviations of SIC for the experimental and control groups in the peer-reviewed articles. Data in the form of charts only were extracted using Get Data Graph Digitizer software (Shanghai, CHN).

2.2. Data Analysis

The natural logarithm of the response ratio (*RR*) is used as the effect size (ln*RR*) [40] and is calculated as follows:

$$lnRR = ln\left(\frac{\overline{X_E}}{\overline{X_C}}\right) = ln\left(\overline{X_E}\right) - ln\left(\overline{X_C}\right) \tag{1}$$

where $\overline{X_E}$ and $\overline{X_C}$ are the mean result values of the experimental and control groups, respectively.

We calculate the corresponding variance (v) using the following formula:

$$v = \frac{{S_E}^2}{N_E\overline{X_E}^2} + \frac{{S_C}^2}{N_C\overline{X_C}^2} \tag{2}$$

where S_E and S_C are the standard deviations of the experimental and control groups, respectively, and N_E and N_C are the numbers of samples in the experimental and control groups.

When the 95% CI overlapped with 0, the difference between the results of the experimental and control groups was non-significant; when the 95% CI did not overlap with the invalid line, the mean effect sizes were considered to be significant. To show the effects more clearly, we converted the effect size (lnRR) to the relative change rate (Y), which was calculated as follows:

$$Y = \left(e^{\mathrm{lnRR}} - 1\right) \times 100\% \quad (3)$$

where a positive value of Y means that the measure improves the SIC content and soil physicochemical properties of dryland fields compared to the control treatment, and a negative value means the opposite. If the 95% CI of the Y value overlapped with 0, the effect of the measure on the SIC content and soil physicochemical properties of dryland fields is considered to be non-significant compared to the control treatment, while in the opposite case, the effect is significant. In each subgroup analysis, differences between subgroups were considered significant if the 95% CI for each Y value within the different subgroups did not overlap, and vice versa for non-significant differences between groups. This study used MetaWin (New York, USA) software for integration analysis and Microsoft Exce1 2010 software (Redmond, USA) and Origin 2018 software (Northampton, USA) for database building and plotting, respectively.

3. Results

3.1. Distribution of SIC Contents under Different Agronomic Practices

The statistical characteristics of the SIC content of dryland fields show (Figure 1) that the kurtosis and skewness of the data for SIC contents are 3.26 and 1.22, respectively, and the distribution curve of SIC content is right skewed. The median value of SIC content is 43.95 g kg^{-1}, which is a relatively significant difference compared to the mean value of 45.11 g kg^{-1}, indicating that SIC is unevenly distributed within the dryland field regions of the world and is susceptible to different farmland management practices, climate, terrain, outliers and other factors.

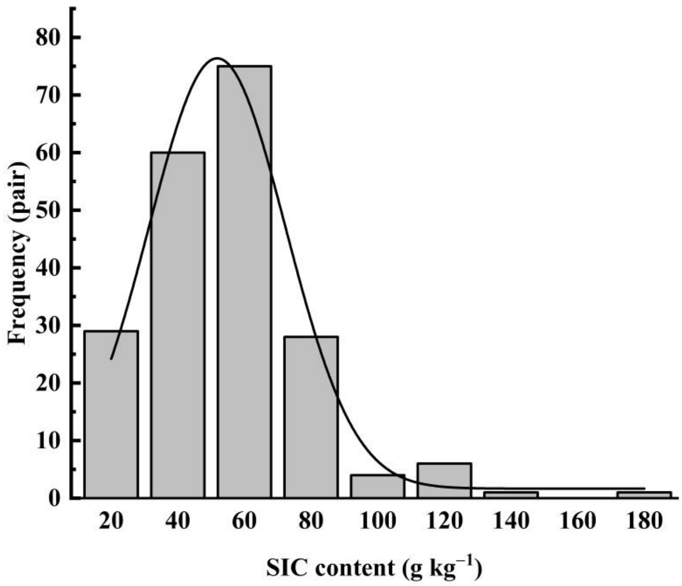

Figure 1. Frequency distribution histogram of SIC content.

The mean values of SIC content under the three management practices of NT, NTS and PM were 51.43 g kg^{-1}, 55.13 g kg^{-1} and 49.33 g kg^{-1}, respectively, which were all significantly higher than the content under the respective CT treatments (43.85 g kg^{-1}, 32.86 g kg^{-1} and 45.23 g kg^{-1}). The changes in SIC content under the two management practices of M and SM were the same, and the mean values (52.42 g kg^{-1} and 43.49 g kg^{-1}) were less than those with CT (57.88 g kg^{-1} and 44.96 g kg^{-1})(Figure 2).

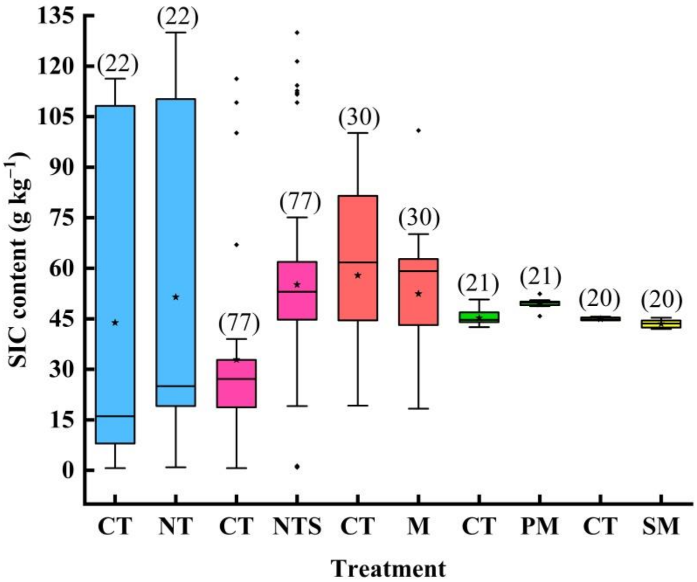

Figure 2. SIC content under different agronomic practices. The x-axis from left to right indicates the SIC content of the experimental and control groups (CT) under NT, NTS, M, PM and SM, respectively. The numbers in brackets represent sample sizes. The "★" in the graph represent mean values and the dots represent outliers.

3.2. Effect of No-tillage and No-tillage Straw Return on SIC Contents of the Plough Layer of Dryland Field

The analysis results indicate (Figure 3) that both NT and NTS increase the SIC content of the plough layer of dryland fields, with the enhancement effect being NTS > NT. The ln*RR* of the SIC content of the 0- to 40-cm plough layer of the dryland field after NT treatment was 0.14 ± 0.03, indicating that NT could increase the SIC content of the 0- to 40-cm plough layer by 15.07 ± 3.48% compared to CT. The ln*RR* of SIC contents of the 0- to 40-cm plough layer of dryland field after NTS treatment was 0.57 ± 0.032, indicating that NTS with reduced tillage disturbance significantly increased the SIC content of the 0- to 40-cm plough layer by 77.34 ± 5.6% compared to CT with frequent disturbances.

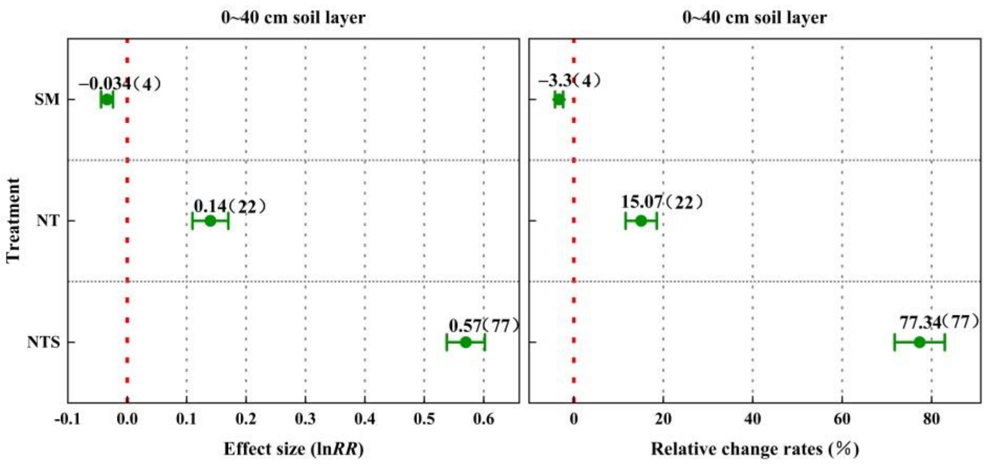

Figure 3. Effects of SM, NT and NTS on the SIC content of the plough layer. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

3.3. Effect of Organic Manure on the SIC Contents of the Plough Layer of Dryland Field

The analysis of SIC content data from long-term localization experiments on dryland fields in China and other dryland areas (Figure 4) showed that the variation of ln*RR* of SIC contents in the 0- to 40-cm plough layer of dryland fields after the M treatment ranged from −0.054 to −0.02. Among the findings, the ln*RR* of SIC content at 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm were −0.054 ± 0.0217, −0.035 ± 0.0223, −0.031 ± 0.0234 and −0.020 ± 0.0256, respectively. Compared with CT, all layers of soil showed some reduction in SIC content after M treatment, with 5.23 ± 2%, 3.35 ± 2.2%, 3.01 ± 2.25% and 1.94 ± 2.5% reductions, respectively, and the deeper the soil layer, the smaller the reduction, but the difference was not significant.

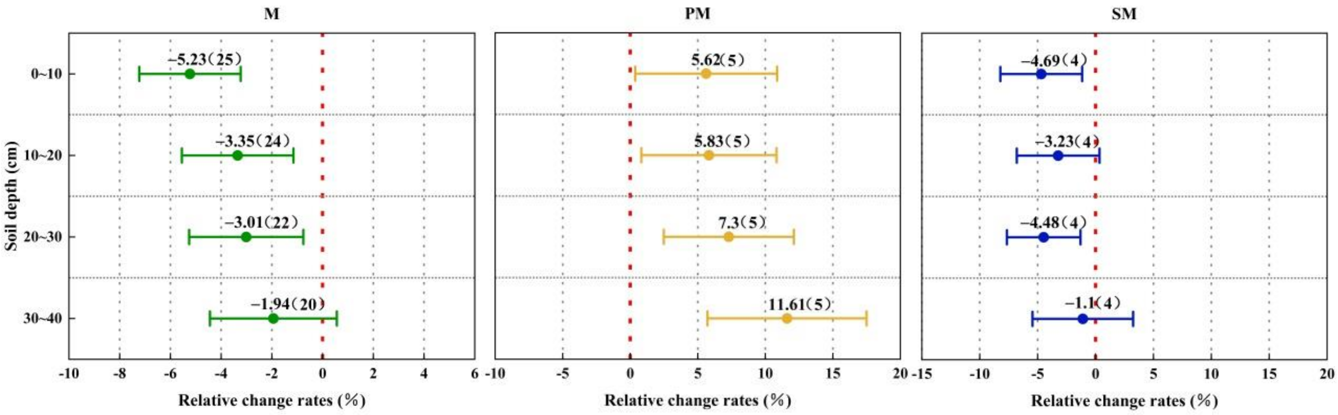

Figure 4. Effects of M, PM and SM on the SIC content of the plough layer. The points in the first row of graphs represent effect sizes, and the points in the second row of graphs represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

3.4. Effect of Plastic Film Mulching and Straw Return Mulching on the SIC Contents of the Plough Layer of Dryland Field

The main land cover methods are PM and SM, and different cover methods cause differences in the SIC content of the plough layer of dryland fields (Figure 4). The difference in the growth rate of SIC content in the whole plough layer showed that PM > SM. The variation of ln*RR* in SIC content in the 0- to 40-cm plough layer of dryland fields after PM treatment ranged from 0.05 to 0.11 (Figure 4). Among the findings, the ln*RR* of SIC content at 0−10 cm, 10−20 cm, 20−30 cm and 30−40 cm were 0.05 ± 0.053, 0.06 ± 0.045, 0.07 ± 0.047 and 0.11 ± 0.05, respectively. Compared with CT, the SIC content in each layer increased significantly after PM treatment, with increases of 5.62 ± 5.25%, 5.83 ± 5%, 7.30 ± 4.81% and 11.61 ± 5.89%, respectively, and the deeper the soil layer, the greater the increase. The variation of ln*RR* of SIC content in the 0- to 40-cm plough layer of dryland fields after SM treatment ranged from −0.05 to −0.01 (Figure 4), and the ln*RR* of SIC content in the 0- to 40-cm plough layer was −0.034 (Figure 3), with a decrease of 3.3% compared with CT. Among the findings, the ln*RR* of SIC content at 0−10 cm, 10−20 cm, 20−30 cm and 30−40 cm were −0.05 ± 0.037, −0.03 ± 0.037, −0.05 ± 0.033 and −0.01 ± 0.044, respectively, showing a non-significant decrease in the SIC content of all layers after SM treatment compared to CT, with decreases of 4.69 ± 3.53%, 3.23 ± 3.57%, 4.48 ± 3.18% and 1.1 ± 4.35%, respectively.

4. Discussion

4.1. Effect of Organic Manure, Straw Return Mulching and Plastic Film Mulching on the Distribution of SIC in the Plough Layer of Dryland Field

Changes in SIC are directly controlled by anthropogenic disturbances (tillage, fertilization, mulching), environmental conditions (soil pH, soil respiration, soil moistures contents, soil porosity, soil CO_2 partial pressure) and some physicochemical reactions (leaching, dissolution, precipitation) [41,42]. Some researchers have suggested that soil pH is one of the critical factors affecting SIC content, that, when soil pH decreases, SIC is more easily dissolved and converted into CO_2, and that SIC content appears to increase with increasing soil pH [31,43]. Some studies have pointed out that M may increase SOC, which is used by soil microorganisms to release more CO_2, resulting in an increase in the partial pressure of CO_2 in the soil and a decrease in soil pH, which reduce soil acidity and promote the decomposition of SIC and the reduction in its contents [33,44]. Li [34] suggested that SM additionally increased SOC, leading to a significant decrease in soil pH, which reduced the SIC content. However, it has also been concluded that the effects of M and SM on soil pH in drylands were non-significant [45], similar to the results of this study. The results of the statistical analysis in this study showed that M did not have a strong effect on soil pH at 0–40 cm of dryland fields, and the reduction in soil pH was not strong, with an average reduction of only 0.26 compared to the control (Figure 5). The reduction in soil pH in the 0- to 40-cm soil layer of the dryland field by SM was also non-significant at 0.16 (Figure 5), indicating that the effects of both M and SM practices on soil pH were not major factors in the change of SIC content in dryland fields.

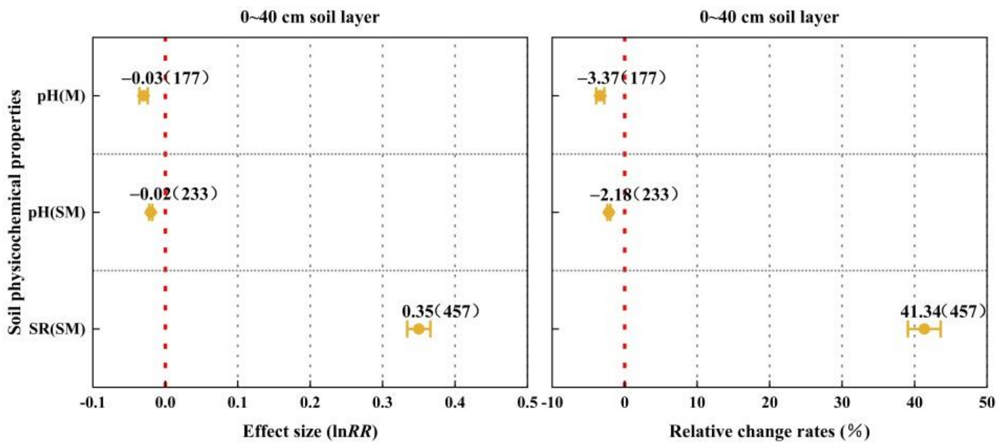

Figure 5. Effects of M and SM on soil pH and those of SM on soil respiration. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

In arid and semi-arid areas, SOC is mainly transferred to SIC through the SOC-CO_2-$CaCO_3$ pathway, and dryland soil is rich in calcium ions, which react with bicarbonate (HCO−3) when dissolved in soil water to produce more $CaCO_3$ precipitates [29], while abundant SOC facilitates CO_2 release and significantly increases CO_2 partial pressure in the soil; when dissolved in water, CO_2 forms large amounts of bicarbonate (HCO−3) and carbonic acid (H_2CO_3), which react with calcium ions to increase the SIC content [33]. M and SM can significantly increase the SOC content, and the excellent warming and water retention effects also further increase the activity of soil microorganisms, which promotes the decomposition of SOC and enhances the CO_2 partial pressure [33]. In this study, we found that organic matter, such as SM, significantly increased soil respiration in the 0- to 40-cm plough layer of dryland field by 41.34 ± 2.3% (Figure 5), which promoted the increase in CO_2 concentration in the soil and facilitated the increase in SIC contents. However, due to the improved effects of M and SM on soil aeration [45], coupled with the effect of tillage on increasing soil aeration (Figure 6), it is not conducive to the conservation of CO_2, resulting in more CO_2 entering the atmosphere and more atmosphere entering the soil, reducing the partial pressure of CO_2 in the soil and promoting soil carbonate dissolution [46,47]. Due to the offsetting effect of these two positive and negative effects, the SIC content of dryland fields at 0–40 cm showed a non-significant reduction trend after M and SM treatments.

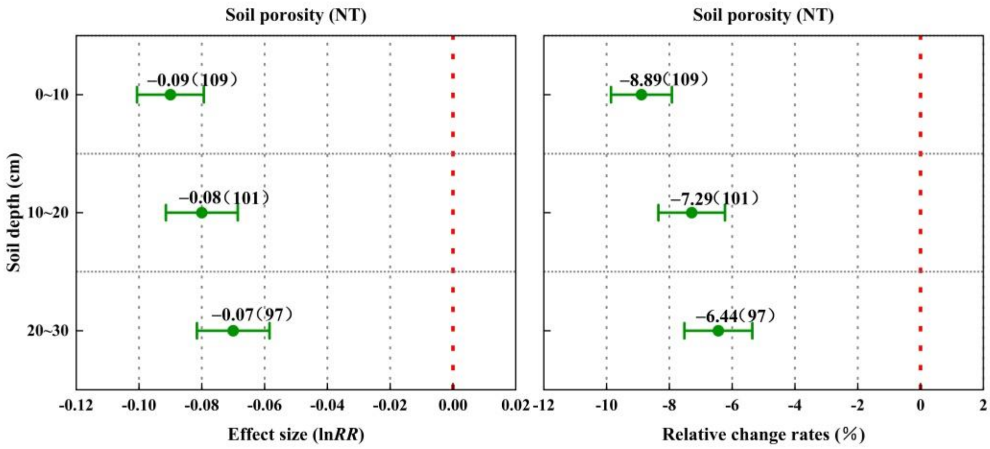

Figure 6. Effect of NT on soil porosity. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

In this study, it was found that PM not only significantly increased the SIC content in the 0- to 40-cm plough layer of dryland field by 5.62 ± 5.25% to 11.61 ± 5.89% (Figure 4), but it also increased the water contents in the 0- to 20-cm and 20- to 40-cm layers of dryland field by 13.12 ± 2.27% and 10.25 ± 2.32% (Figure 7), respectively, which promoted the leaching of SIC in the top layer of soil, showing that the deeper the soil layer, the higher the SIC content. This outcome may be due to the warming and water retention effects of PM promoting SOC degradation, reducing SOC content [34], facilitating the transfer of SOC to SIC through the conversion pathway of SOC-CO_2-$CaCO_3$ and increasing SIC content [29]. PM can also significantly increase the water content of dryland soil, facilitating SIC leaching into deeper soil layers and showing a gradual increase in the accumulation of SIC with deeper soil layers [34].

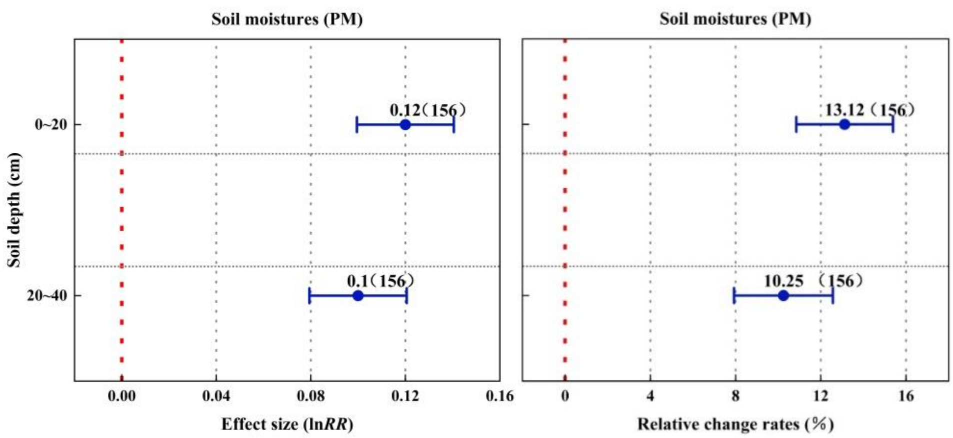

Figure 7. Effect of PM on soil moistures content. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

4.2. Effects of No-tillage and Its Synergistic Effect with Straw Returning on SIC of Plough Layer in Dryland Field

The results of the present study (this study used meta-analysis to analyze SM, NT and NTS separately for different sample sizes, and the resulting analysis accurately reflected the same trends as the original data) showed that NT alone significantly reduced the porosity of the soil in the 0- to 10-cm, 10- to 20-cm and 20- to 30-cm layers of dryland fields by 8.89 ± 0.97%, 7.29 ± 1.06% and 6.44 ± 1.08%, respectively (Figure 6), and significantly increased the SIC content of the 0- to 40-cm layer of dryland fields by up to 15.07 ± 3.48%

(Figure 3). This outcome may occur because long-term tillage exposes the soil's calcium-bearing layer to the external environment, accelerating carbonate weathering and leading to loss of SIC [46,47]; NT not only reduces the possibility for loss of exposure of the soil's calcium-bearing layer but also reduces the occurrence of SIC dissolution in the upper plough layer and consequent re-precipitation in the deeper layers, while reducing the aeration of the soil (Figure 6) and reducing CO_2 dissipation to the atmosphere [46], which is very conducive to the formation and preservation of SIC and promotes the enhancement of SIC content. Moreno [23] found that the SIC content at all depths of the NT-treated dryland field was significantly higher than that of CT after a long-term positioning experiment.

Further analysis in this study found that, although NT could increase SIC content by about 15%, and SM did not have a significant effect on SIC content (Figure 3), a significant increase in SIC content from 0 to 40 cm was observed under the combined use of both practices (NTS), which could reach 77.34 ± 5.6% (Figure 3), showing a strong synergistic promotion effect. This effect may occur because, on the one hand, SM promotes soil respiration (Figure 5) through the massive supplementation of organic carbon sources and the improvement of soil hydrothermal conditions [34], which increase soil CO_2 concentration and facilitate the conversion of SOC into SIC [29], and NT avoids the effect of tillage on soil aeration (Figure 6), which makes soil CO_2 less likely to dissipate into the atmosphere and reduces atmosphere entry into the soil, ensuring that the CO_2 partial pressure in the soil is at a high level and enhances the SOC-CO_2-$CaCO_3$ conversion pathway [24]. On the other hand, when straw enters the soil, soil exchangeable Ca^{2+} and Mg^{2+} increase significantly, especially Ca^{2+} [48] (Figure 8); SM reduces soil water evaporation and increases soil water holding capacity [49,50], and NT disturbs the soil less and improves soil structure [51,52]; thus both NT and SM were beneficial in increasing soil surface water content (Figure 9), and the combination of NT and SM (NTS) further improved soil structure and soil water holding properties [53], resulting in higher soil surface water content (Figure 9), showing a synergistic contribution.

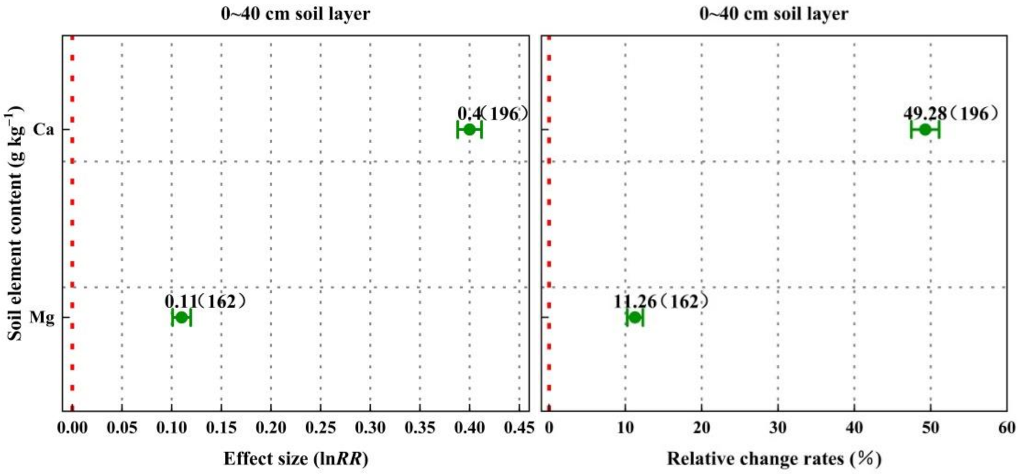

Figure 8. Effects of SM on soil Ca and Mg. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

High partial pressure conditions of CO_2 in the soil are maintained by the synergistic effects of SM and NT on CO_2 production and conservation, and NTS is more effective in increasing the surface water content of the soil than NT and SM (Figure 9). Therefore, the dissolution of CO_2 in soil air under NTS conditions will form large amounts of bicarbonate (HCO−3) and carbonic acid (H_2CO_3) when occurring in soil water [Equation (4)], and SM significantly increases soil exchangeable Ca^{2+} and Mg^{2+} (Figure 8), which may generate more $CaCO_3$ or $MgCO_3$ precipitates [Equation (5)]. As a result, NTS showed a more substantial enhancement of SIC content compared to NT and SM (Figure 3). The strong enhancing effect of NTS on SIC content has also been confirmed by the results of several studies [24,46,47]. Furthermore, due to the similarity of the effects of M and SM treatments on soil, it is inferred that NT and M should also make strong synergistic contributions to the SIC content, but further research and analysis are needed for the relevant components.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO3^- \quad (4)$$

$$2HCO_3{}^- + Ca^{2+}(orMg^{2+}) \leftrightarrow CaCO_3(orMgCO_3) + H_2O + CO_2 \quad (5)$$

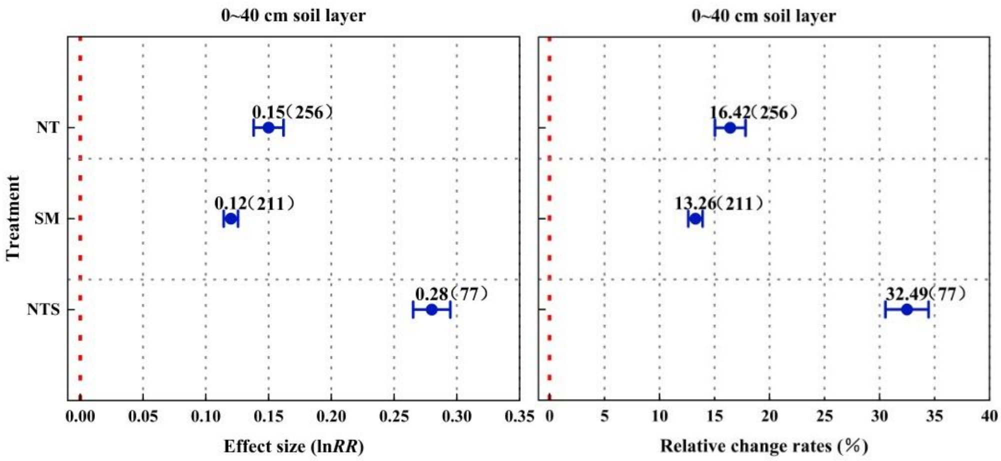

Figure 9. Effects of NT, SM and NTS on soil moisture content. The points in the graph on the left represent effect sizes, and the points in the graph on the right represent relative change rates. Error bars indicate 95% confidence intervals. The numbers in brackets represent sample sizes.

5. Conclusions

The results of the meta-analysis indicated that different agronomic practices had different effects on the SIC content in the 0- to 40-cm plough layer of dryland fields and affected the SIC in dryland farmland by altering different physicochemical properties. SM and M had a non-significant tendency to reduce the SIC content through the positive and negative offsetting effect of soil respiration and soil porosity. NTS, NT and PM contributed to promoting SIC content in the 0- to 40-cm plough layer of dryland field through different mechanisms. NT not only reduced the possibility of a loss of exposure of the soil's calcium-bearing layer, but it also reduced the occurrence of the dissolution of SIC in the upper tillage layer and its re-precipitation in the deeper layers while reducing the aeration of the soil and the loss of CO_2 to the atmosphere, which was very beneficial for the formation and preservation of the SIC. PM's warming and water retention effect promoted SOC degradation and reduced SOC content, facilitating the transfer of SOC to SIC through the SOC-CO_2-$CaCO_3$ conversion pathway and increasing SIC content. NTS had the most substantial effect on SIC enhancement in the dryland fields through the synergistic effects of NT and SM. The intensity of the five agronomic measures was NTS > NT > PM > SM > M. Therefore, NTS treatment of dryland fields can significantly increase the SIC content and was conducive to enhancing the drought resistance of dryland crops and improving dryland crop yields and the ability of dryland fields to sequester carbon and reduce emissions.

Author Contributions: Conceptualization, X.N., Y.L., W.D., Y.Y., J.D., Y.M. and L.W.; methodology, X.N., Y.L., W.D., Y.Y., J.D., Y.M. and L.W.; acquisition of data, analysis and interpretation of data, X.N.; writing—original draft, X.N.; writing—review and editing, X.N., Y.L. and W.D.; formal analysis, X.N., Y.L. and W.D.; resources, supervision, funding acquisition, Y.L. and W.D. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Ordos City Science and Technology Cooperation Major Special Project (Grant No. 2021EEDSCXQDFZ012).

Data Availability Statement: The data presented in this study are available.

Acknowledgments: We would like to thank the reviewers and editors for their proofreading and helpful suggestions on the manuscript. We express heartfelt thanks to the scientists whose research reports were included in this meta-analysis.

Conflicts of Interest: The authors declare no conflict of interest.

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