Effects of Straw Mulching Thickness on the Soil Health in a Temperate Organic Vineyard

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Abstract: Soil mulching is one of the common measures applied in organic agricultural production which could replace plastic films and protect the environment. In order to fully evaluate the effects of different straw mulching thicknesses on soil health, maize straw was mulched with the thicknesses of 0 cm (CK), 2 cm, 4 cm and 6 cm on soil surface to assess the effects on soil temperature (ST) and moisture (SM), soil pH, soil organic carbon (SOC), total nitrogen (TN), C/N, soil aggregates and soil bulk density (SBD) in a temperate organic vineyard. We found that straw mulching had a significant regulating effect, with soil moisture being elevated with increasing mulching thickness by 5.8%, 9.0% and 11.1% compared with CK. The soil SOC content increased by 3.0%, 2.4% and 2.3%. Although soil pH and C/N significantly (p < 0.05) increased, they fluctuated with increasing mulch thickness. Straw mulching also increased the content of >2 mm soil particle size and elevated the mean weight diameter (MWD) and geometric mean diameter (GMD). The increasing mulching thickness prolonged the effect on the stability of soil aggregates. The 4 cm maize straw mulching thickness has the best effect for ecologically and environmentally managing warm-temperate organic vineyards so it may have a great application prospect on a global scale.

Keywords: soil property; organic management; agricultural waste utilization

1. Introduction

Grapes are widely planted as horticultural plants which are intensively produced globally. However, such an intensive production model does not take its negative impact on soil health into account, which decreases the sustainability of vineyard development [1]. Organic farming is believed to be environmentally friendly and has a number of ecological functions, such as improving soil quality, increasing biodiversity, reducing greenhouse gas emissions, saving energy, preventing eutrophication of water, and ensuring the safety of agricultural products [2–4]. In 2019, some 468,000 hectares of organic grapes were planted around the world, 85% of which were located in Europe and only 14,000 hectares in China, accounting for 3% of the world’s organic grape area and 0.19% of China’s grape area [5,6]. The development of the organic model in China has been facing various problems in terms of policy, higher labor input, marketing and production technology. Therefore, technical research needs to be strengthened to solve these problems [7,8].

China uses more than 340 billion m³ of water per year for agricultural irrigation [9]. Due to simple irrigation techniques, low irrigation efficiency and water scarcity, agricultural plants in China consume a large amount of water resources, leading to ecological and environmental problems and increasing the cost of agricultural input [10]. For instance, the core grape production area of Helan Mountain plants is 29,653 hectares and needs 1.59 billion tons of water, which is heavily dependent on the transit water resources of the Yellow River [11]. Although Shandong Province is located in the warm-temperate
monsoon zone, it still faces the risk of time dimension between the water requirement and the precipitation because of the larger grape plant area and the lower matching degree of precipitation spatial and temporal distribution [5,12,13]. To avoid such kinds of shortness, farmers generally use plastic film mulching to maintain moisture and temperature, however this has led to serious plastic pollution. In addition, the production and management model of farmers is influenced by various factors, such as literacy, specialization, years of cultivation, gender and vineyard characteristics. These factors also affect farmers’ behavior on the application of fertilizers, pesticides and plastic film, which can cause serious soil pollution [14–16]. Therefore, a safer, healthier and more sustainable grape production model is urgently needed for modern viticulture [17,18].

Soil mulching is one of the common measures in agricultural production. It is an important component of integrated organic farming management and includes grass mulching, plastic mulching and agricultural waste mulching [19,20]. The grass mulching method involves planting legumes or local herbs in the vineyard by regular mowing or no mowing [4,21,22]. Although plastic mulching is low cost and easy to use, it is difficult to be naturally depredated, which can cause microplastic pollution [23,24]. Using agricultural waste instead of plastic films not only improves the physical properties of the soil but also increases the soil nutrients. Our previous investigation revealed that the total amount of agricultural waste is abundant and contains a higher total nitrogen content, with crop straw accounting for 22.9% [25]. Agricultural waste mulching such as maize straw, oat straw, wheat straw, etc. has the function of heat preservation and water retention which could reduce environmental pollution, make full use of biomass, improve soil physical and chemical properties and the structure of soil aggregates, and increase the added value of agricultural products [19,26–29]. The rational use of straw is of great significance both in reducing environmental pollution and achieving the goal of carbon reduction and carbon neutrality [30]. Therefore, China has proposed the implementation of straw comprehensive utilization, with the goal of reaching an 86% straw comprehensive utilization rate nationwide in 2025 [31], as straw mulching is an effective way in achieving the abovementioned goals.

Straw mulching on the soil surface has been proven to have the function of improving the physical structure, chemical properties and biological properties of soil [32], and is a specific practice to adapt to future climate change and sustainability [33]. It is also an effective way of using agricultural waste for disposal [34]. The selection of mulch materials must consider local climatic conditions and integrate their impacts on agroecosystem functions and soil health [1,35]. The sustainability of production systems in viticulture is involved in economic, social and environmental aspects [8], and researchers found that financial benefit can rise from saving production costs and yield improvements [18]. In addition, the vineyard management is one of the production inputs, and the cost increases as the amount straw mulching increases [27,36]. So, there is a need to find a balance between the cost and the efficiency of the thickness of straw mulch [37]. To what extent the thickness of straw mulching can be used to obtain suitable and stable soil temperatures and moisture in vineyards, improve soil structure and health, and eliminate environmental pollution and agricultural waste pollution is the focus of this paper.

To analyze the effects of straw mulching on the physical and chemical properties of vineyards, solve the dilemma of soil pollution in the conventional model and comprehensively using straw waste, and provide a solution for global organic vineyard management, we have carried out research on the effects of different mulching thicknesses on soil health, then explored technical support for a comprehensive and correct evaluation of the effects of different soil mulching. Finally, we summarized the key indexes to provide a theoretical basis and technical support for the sustainable management of table grapes.
2. Materials and Methods

2.1. Study Area

The experiment was carried out in Jiangjiazhuang, Pingyi County, Linyi City, Shandong Province (35°26′23.13″ N, 117°49′51.58″ E) from 2019 to 2020. Large interannual differences in precipitation and temperature were observed in the study area. The highest monthly mean temperatures during the experiment were 27.6 °C in July 2019 and 27.1 °C in August 2020. The highest monthly rainfall was in August, at 509.9 mm and 442.6 mm, in 2019 and 2020, respectively. The interannual precipitation at the trial site varied considerably, with concentrated rainfall in 2019 and dispersed rainfall in 2020 (Figure 1).

![Average daily temperature and precipitation in 2019–2020.](image)

**Figure 1.** Average daily temperature and precipitation in 2019–2020.

2.2. Experimental Design

A gradient of thickness of 2 cm (7.06 t ha⁻¹ y⁻¹), 4 cm (14.13 t ha⁻¹ y⁻¹), and 6 cm (21.19 t ha⁻¹ y⁻¹) maize straw mulching treatments were set up in the vineyard under organic conditions, with the treatment without maize straw as the control (CK, 0 cm or 0 t ha⁻¹ y⁻¹). The maize straw was mulched on the soil surface in the budbreak stage [38]. The study was conducted using completely randomized treatments with three replicates for each treatment. The main characteristics of the sampled soil were as follows: pH 5.28, total nitrogen (TN) 0.99 mg g⁻¹, and soil organic carbon (SOC) 6.41 mg g⁻¹ in the 0–20 cm soil layer and pH 4.94, TN 0.58 mg g⁻¹, SOC 3.12 mg g⁻¹ in the 20–40 cm soil layer.

2.3. Soil Sampling and Measurements

2.3.1. Soil Properties

Soil temperature and soil moisture were measured by TR-6D (Shunkeda Ltd., Dongwan, China). The measurement period is adjusted from Sun et al. (2018) [39], whereby the measurement period in this study was five consecutive days (except rainy) in three different stages in 2019 and 2020, respectively. All the measurements were carried out at the depth of 7 cm under the soil surface.

Soil samples were taken from each of the 4 treatments in each main growing season (May–September) in 2019 and 2020 to measure the soil pH, TN and SOC at depths of 0–20 cm and 20–40 cm. The soil pH was measured by PB-10 (Sartorius, Germany), the TN was measured by the Kjeldahl method [38], and SOC was measured by the K₂Cr₂O₇–H₂SO₄ digestion method [29].
2.3.2. Soil Aggregate

Soil aggregates were determined after harvest, and 0–20 cm soil samples were divided into >2 mm, 1–2 mm, 0.5–1 mm, 0.25–0.5 mm, 0.053–0.25 mm and <0.053 mm by the wet sieving method. The mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated as described by Ren et al. (2022) [40].

2.3.3. Soil Bulk Density

Soil bulk density (SBD) was determined by the cutting ring method [40]. It was assessed at the end of the experiment, the 0–40 cm soil layer was divided into 8 layers. The volume of the stainless steel ring used in each plot was 100 cm³.

2.4. Statistical Analyses

Data were analyzed using EXCEL, SPSS 22.0 and OriginPro 2020 for different treatments in the same year using one-way analysis of variance (ANOVA) for significance \((p < 0.05)\) and independent samples \(t\)-test for significance \((p < 0.05)\) for different years in the same treatment. OriginPro 2020 was used to make the graphs.

3. Results

3.1. Soil Temperature and Moisture

The ranges of soil moisture variation for the different treatments were 15.93–37.37\% for CK, 19.43–33.11\% for the 2 cm straw mulching treatment, 20.69–31.57\% for the 4 cm straw mulching treatment and 20.71–31.39\% for 6 cm straw mulching treatment. The ranges of soil moisture variation for different treatments were 21.45\%, 13.68\%, 10.89\% and 10.68\% for the 0 cm, 2 cm, 4 cm, and 6 cm straw mulching treatments, respectively. Soil moisture in the different treatments varied in three ways over time. First, it was noted that CK treatment was lower than in 2 cm, 4 cm, and 6 cm straw mulching treatments in lower temperature environments. Soil moisture was significantly \((p < 0.05)\) lower in CK than in the 2 cm, 4 cm, and 6 cm straw mulching treatments. Soil moisture increased with the increasing mulch thickness (Figure 2A,B,D). Second, soil moisture fluctuated with increasing mulch thickness in medium temperature environments. It increased first and then decreased without significant difference \((p > 0.05)\) in the 2 cm, 4 cm, and 6 cm straw mulching treatments (Figure 2E), and it decreased first in the 2 cm and 4 cm straw mulching treatments without significant difference \((p > 0.05)\) and then significantly \((p < 0.05)\) increased the soil moisture in the 6 cm straw mulching treatment (Figure 2F). Third, CK had significantly \((p < 0.05)\) higher soil moisture than in the 2 cm, 4 cm and 6 cm straw mulching treatments in higher temperature and large precipitation environments (Figure 2G–L). We found that soil temperature decreased (Figure 2G,H) or increased (Figure 2I,J) with increasing mulch thickness. However, sometimes it still fluctuated, with 4 cm straw mulching treatment being the peak of soil temperature (Figure 2K). In addition, 6 cm straw mulching treatment and 2 cm, 4 cm mulching treatments had significant differences \((p < 0.05)\) in Figure 2H,K,L. In total, the trend was more obvious in 2020. The average soil moisture of the 2 cm, 4 cm and 6 cm straw mulching treatments increased with increasing mulching thickness by 5.8\%, 9.0\% and 11.1\% of CK and was decreased by 3.4\%, 2.9\% and 1.8\%, respectively, on average soil temperature.
Figure 2. The effects of different treatments on soil moisture and temperature. (A)–(F) represent the average soil moisture ± standard error of 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in different stages in 2019 and 2020. (G)–(L) represent the average soil temperature ± standard error of 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in different stages in 2019 and 2020 (the soil moisture and temperature were measured in 7 cm depth under soil surface, n = 3, p < 0.05).

3.2. Soil Properties

The soil pH, TN, SOC and C/N were all higher in the 0–20 cm soil layer than in the 20–40 cm soil layer (Figure 3). Soil pH decreased and then increased with increasing mulch thickness in the 0–20 cm soil layer. The soil pH was significantly (p < 0.05) higher in CK than in the 2 cm, 4 cm, and 6 cm straw mulching treatments by 1.1%, 4.1% and 0.71%, respectively, in 2019. In contrast, it was significantly (p < 0.05) higher in the 2 cm, 4 cm, and 6 cm straw mulching treatments than in CK by 2.2%, 1.1% and 3.8%, respectively, in the year of 2020 (Figure 3A). In the 20–40 cm soil layer, the soil pH in the 6 cm straw mulching treatment was significantly (p < 0.05) higher than that in the CK and 2 cm treatments. Straw mulching also had a significant (p < 0.05) effect on TN. For instance, in 2020, the TN content decreased significantly (p < 0.05) with increasing straw mulch thickness by 5.0%, 5.4% and 6.9%, respectively, with 6 cm straw mulching treatment having the lowest value of 1.39 mg g\(^{-1}\). TN from 20–40 cm was significantly (p < 0.05) higher in the CK treatment than in the 2 cm, 4 cm, and 6 cm treatments. In the 0–20 cm soil layer, TN increased during the two years and was 0.23 mg g\(^{-1}\), 0.13 mg g\(^{-1}\), 0.21 mg g\(^{-1}\) and 0.10 mg g\(^{-1}\) for the 0 cm, 2 cm, 4 cm, and 6 cm straw mulching treatments, respectively. For the 20–40 cm soil layer, they were 0.07 mg g\(^{-1}\), 0.03 mg g\(^{-1}\), 0.02 mg g\(^{-1}\) and 0.09 mg g\(^{-1}\), respectively (Figure 3B,F). Straw mulching had a significant effect on SOC. In 2019, the SOC content of the 0–20 cm soil increased with increasing mulching thickness by 1.2%, 7.1% and 11.4%, respectively. The 4 cm and 6 cm straw mulching treatments had significantly higher SOC than CK, by 0.62 mg g\(^{-1}\) and 1.0 mg g\(^{-1}\), respectively. However, in 2020, there was no significant (p > 0.05) difference among different treatments. CK had the lowest SOC, and the 2 cm, 4 cm, and 6 cm treatments were higher by 3.0%, 2.4% and 2.3%, respectively, than CK. For the 20–40 cm soil layer, SOC was significantly (p < 0.05) higher in the 6 cm straw mulching treatment than in CK (Figure 3C,G). Straw mulching also had a significant effect on the soil C/N, fluctuating with the increasing straw mulching thickness. The 4 cm and 6 cm straw mulching treatments were found to have significantly (p < 0.05) higher C/N in the 0–20 cm soil layer than in CK in
8.27–11.97% (Figure 3D), and the soil C/N in the 2 cm and 6 cm straw mulching treatments was significantly ($p < 0.05$) higher than the CK in the 20–40 cm soil layer.

Figure 3. The effects of different treatments on soil properties. (A)–(D) represent the soil pH, total nitrogen, organic carbon and C/N of the 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in the 0–20 cm soil layer in the two years, and (E)–(H) represent the soil pH, total nitrogen, organic carbon and C/N of the 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in the 20–40 cm soil layer in the two years. Different lowercase letters indicate significant differences among different treatments at $p < 0.05$ level, with * indicating significant differences in the same treatment at $p < 0.05$ level between the different years, and ** indicating significant differences in the same treatment at $p < 0.01$ level between the different years. Mean values ± standard error, $n = 3$. 

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3.3. Soil Aggregate

Among the different particle sizes, the soil composition proportion was the highest in the 0.5–1 mm range in all treatments except for the 4 cm straw mulching treatment in 2020 (Figure 4). The 4 cm straw mulching treatment had the highest particle size in the 0.25–0.5 mm range (Table 1). Among the >2 mm soil particle sizes, the percentage of agglomerate fractions decreased with increasing straw mulch, with the lowest being in CK. Nevertheless, for those <0.25 mm soil particle sizes, CK had a higher percentage than the 2 cm, 4 cm, and 6 cm straw mulching treatments. Among all the soil agglomerate fractions, CK was significantly \( p < 0.05 \) higher than the 2 cm, and 4 cm straw mulching treatments in <0.05 mm particles in 2019, however there was no significant \( p > 0.05 \) difference in 2020. Comparing the changes in composition proportion between the two experimental years, all treatments and decreased the proportion of 0.5–1 mm and 0.053–0.25 mm particle sizes.

![Figure 4](image-url)

**Figure 4.** The effects of different treatments on soil composition proportions.

| Year | Particle Sizes | 0 cm | 2 cm | 4 cm | 6 cm |
|------|----------------|------|------|------|------|
| 2019 | >2 mm          | 3.7 ± 0.12 Ea | 14.63 ± 6.65 ABa | 12.26 ± 4.29 CDa | 8.73 ± 2.25 Da |
|      | 0.5–1 mm       | 14.31 ± 2.56 CDa | 20.17 ± 3.11 Aa | 15.82 ± 1.5 BCa | 12.68 ± 2.35 CDa |
|      | 0.25–0.5 mm    | 29.83 ± 2.07 Aa | 25.33 ± 2.55 Aa | 29.26 ± 1.2 Aa * | 31.25 ± 2 AA |
|      | 0.053–0.25 mm  | 18.74 ± 0.65 Bab | 18.09 ± 0.7 ABa * | 21.52 ± 1.6 Bab | 23.71 ± 1.13 Ba |
|      | <0.053 mm      | 11.91 ± 0.43 Da | 7.03 ± 1.22 Bb | 7.63 ± 1.48 Db | 8.49 ± 1.14 Dab |
| 2020 | >2 mm          | 8.95 ± 3.89 Aa | 12.53 ± 3.72 Ba | 10.87 ± 0.96 Ca | 9.73 ± 1.44 Ba |
|      | 0.5–1 mm       | 20.25 ± 11.1 Aa | 17.29 ± 3.76 ABA | 22.2 ± 5.9 Aa | 13.35 ± 1.83 Ba |
|      | 0.25–0.5 mm    | 26.26 ± 4.73 Aa | 24.03 ± 0.56 Aa | 20.91 ± 2.49 ABA | 28.04 ± 2.2 Aa |
|      | 0.053–0.25 mm  | 19.47 ± 11.82 Aa | 22.86 ± 1.43 Aa | 24.15 ± 0.39 Aa | 27.13 ± 4.86 Aa |
|      | <0.053 mm      | 14.54 ± 5.38 Aa | 13.51 ± 2.69 Ba | 12.27 ± 2.72 BCA | 12.76 ± 0.8 Ba |

* Different capital case letters indicate significant differences among different particle sizes at the \( p < 0.05 \) level, different lowercase letters indicate significant differences among the different treatments at the \( p < 0.05 \) level, and * indicates significant differences in the same treatment at the \( p < 0.05 \) level between the different years. Mean values ± standard error, \( n = 3 \), unit %.

Both the mean weight diameter (MWD) and geometric mean diameter (GMD) of the soil decreased slightly with the increasing mulch thickness, and they were all higher than...
those of CK. The treatment from the 2 cm straw mulching was significantly \( p < 0.05 \) higher than CK in 2019, but there was no significant difference \( p > 0.05 \) in 2020. MWD of 2 cm straw mulching decreased by 0.03 mm and 0.08 mm, respectively, and GMD decreased by 0.04 mm and 0.06 mm, respectively, compared with CK in 2019 and 2020. Meanwhile, 6 cm straw mulching treatment slightly increased either GMD or MWD in both years (Figure 5).

![Figure 5](image)

**Figure 5.** The mean weight diameter (MWD) and the geometric mean diameter (GMD) of soil particles under different mulching treatments. (A) represents the mean weight diameter ± standard error of soil particles in the 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in 2019 and 2020, and (B) represents the geometric mean diameter ± standard error of soil particles in the 0 cm, 2 cm, 4 cm and 6 cm straw mulching treatments in 2019 and 2020. Different lowercase letters indicate significant differences among different treatments at the \( p < 0.05 \) level. \( n = 3 \).

### 3.4. Soil Bulk Density

There was no significant \( p > 0.05 \) difference among the values of soil bulk density (SBD) in the different treatments. The SBD increased with the increasing soil depth. The average SBD of CK was the lowest, with a value of 1.62 g cm\(^{-3}\). However, those of the 2 cm, 4 cm, and 6 cm straw mulching treatments were all at 1.65 g cm\(^{-3}\) (Table 2).

#### Table 2. Soil bulk density of different mulching treatments.

| Soil Layers | 0 cm        | 2 cm        | 4 cm        | 6 cm        |
|-------------|-------------|-------------|-------------|-------------|
| 0–5 cm      | 1.54 ± 0.04 Aa | 1.54 ± 0.07 Aa | 1.42 ± 0.02 Ca | 1.53 ± 0.09 Aa |
| 5–10 cm     | 1.54 ± 0.04 Aa | 1.67 ± 0.02 Aa | 1.6 ± 0.04 Ba  | 1.52 ± 0.13 Aa  |
| 10–20 cm    | 1.61 ± 0.05 Aa | 1.64 ± 0.05 Aa | 1.7 ± 0.04 Aa  | 1.68 ± 0.06 Aa  |
| 20–40 cm    | 1.67 ± 0.05 Aa | 1.68 ± 0.01 Aa | 1.7 ± 0.02 Aa  | 1.69 ± 0.01 Aa  |
| Average     | 1.62 ± 0.01 a  | 1.65 ± 0.02 a  | 1.65 ± 0.02 a  | 1.65 ± 0.04 a  |

Different capital case letters indicate significant differences among the different soil layers at the \( p < 0.05 \) level, and different lowercase letters indicate significant differences among the different treatments in the same soil layers at the \( p < 0.05 \) level. Mean values ± standard error, \( n = 3 \).

### 3.5. Principal Component Analysis of Environmental Factors

The eigenvalue percent of PC1 and PC2 was observed as 48.8% and 25.3% in 2019, and it increased to 54.7% and 27.7%, respectively, in 2020 (Figure 6A,B). CK treatment was positively correlated with soil temperature and TN and negatively correlated with soil moisture, C/N and SOC, while the 6 cm straw mulching treatment was positively correlated with soil moisture and soil C/N and negatively correlated with soil temperature and TN. Soil pH was positively correlated with CK and negatively correlated with the 4 cm and 6 cm straw mulching treatments in the first year, while the opposite was true in the second year. Table 3 shows the results of the principal component analysis of the soil quality indicators.
was rapid in the beginning by decomposing the easily decomposed material, and then

Table 3. Results of the principal component of the soil quality indicators.

| Variable                                | PC1     | PC2     | PC1     | PC2     |
|-----------------------------------------|---------|---------|---------|---------|
| Soil pH (pH)                            | -0.39454| 0.13589 | 0.39693 | -0.10936|
| Total nitrogen (TN)                     | -0.21684| 0.18314 | -0.45054| 0.11804 |
| Soil organic carbon (SOC)               | 0.30817 | -0.43621| 0.33714 | 0.3034  |
| Soil C/N (C/N)                          | 0.37391 | -0.45689| 0.47176 | 0.05897 |
| Soil temperature (ST)                   | 0.38239 | 0.05148 | 0.42634 | -0.10818|
| Soil moisture (SM)                      | -0.45412| -0.09736| -0.34593| 0.05719 |
| Mean weight diameter (MWD)              | 0.30945 | 0.53757 | 0.04184 | 0.65682 |
| Geometric mean diameter (GMD)           | 0.33813 | 0.49786 | 0.00746 | 0.65741 |

4. Discussion

Soil temperature and moisture are influenced by weather conditions. The precipitation intensity under a warming climate may threaten grape quality and yield [41,42]. In our experiment, straw mulching treatments had great effects on regulating soil temperature and moisture (Figure 2). Compared with CK treatment, the soil moisture increased along with the thickness of straw mulching, which was consistent with the results of previous studies [29]. When rainfall is concentrated, straw mulching can maintain soil moisture in a stabilized range, while the soil moisture from CK is too high and easily causes soil erosion [37]. The straw mulching reduced the soil temperature and could keep the soil temperature stable [43], so straw mulching could reduce the effects of extreme weather such as cold waves, storms, and heatwaves, and CK had the highest daily ranges of soil temperature and exist those threaten of extreme weather [44,45]. The ideal hydrothermal conditions maintained by the straw mulch could accelerate straw decomposition, consume agricultural waste and reduce environmental disturbance from agricultural production [46,47].

Maize straw mulching had a significant advantage in increasing SOC and C/N contents (Figure 3), which would improve soil microbial community structure [48,49]. In this experiment, SOC in the 2 cm, 4 cm, and 6 cm straw mulching treatments was higher than that in CK (Figure 3). In 2019, SOC increased with increasing straw mulching thickness, and in 2020, TN decreased with increasing straw mulching thickness, but C/N was increased in both years. The increase in C/N is caused by the release of carbon from the decomposition of maize straw at a faster rate than nitrogen [50]. The decomposition rate of straw mulch was rapid in the beginning by decomposing the easily decomposed material, and then decreased in decomposing lignin and cellulose [51,52] which provided a stable cover for
the soil. The stable soil environment under straw mulch increases soil urease and neutral phosphatase activity and plant-available soil N and Olsen-P content, improves soil nutrient content and promotes plant growth [53]. As a result, the straw decomposition process improves the physical and chemical properties of the soil, promotes the development and stability of agglomerates and causes changes in crop growth characteristics [54].

The status of soil aggregates determines soil health [40]. The higher stability of soil aggregates can strengthen the stability of intra-aggregate and the water infiltration capacity [43]. Our research was consistent with previous research showing that straw mulching improved the uniformity of nutrient distribution for different particle sizes [49]. Now we further found that with the increasing straw mulching, the range of soil composition proportion increased (Figure 4). For the composition proportion of soil aggregates, the proportion of >2 mm soil particle size played a key role in shaping SOC stocks [55], and the aggregates could be better bound under straw addition [56]. Our findings displayed that straw mulching increased the large agglomerate fractions, with 2 cm straw mulching treatment being the highest of the four treatments (Table 1). The proportion of >2 mm soil particle size decreased with increasing straw mulch thickness in the two years. It decreased in the 2 cm and 4 cm treatments with 2.1% and 1.39%, but increased in the 6 cm treatment with 1%, which illustrates that the higher thickness of straw mulch had a long-term effect on soil aggregates. The straw mulching treatments were higher than CK in the proportion of the > 0.25 mm particle size, which was the best size of soil aggregates. The 4 cm straw mulch treatment had the highest proportion of >0.25 mm soil aggregates which could keep the soil structure balance, and CK was the lowest proportion and has the risk of soil erosion [44].

In addition, researchers found that MWD was associated with soil mulch, soil aggregates, water content, soil organic carbon and total nitrogen, and MWD and GMD increased with the straw mulching [57,58]. Here, we found that the 2 cm, 4 cm, and 6 cm straw mulching treatments increased soil MWD and GMD compared with CK (Figure 5), indicating that the soil carbon sequestration improved and had a long-term perspective [49,59]. The 2 cm straw mulching treatment had the highest MWD and GMD in the first year, but it was difficult to maintain in the last year. The 4 cm straw mulching treatment was already higher than that of the 2 cm straw mulching treatment in the second year. The 6 cm straw mulching treatment was reduced compared with the 2 cm and 4 cm straw mulching treatments, indicating that the amount of maize straw used as mulching material had certain limitations [60].

Previous researchers have found that straw mulching could directly influence the SBD but the thickness of straw mulch did not have a linear relationship with SBD [61]. We found that the 4 cm straw mulching treatment had the lowest SBD at 0–5 cm, which was the opposite to CK (Table 2). In addition, low SBD in the soil surface can decrease the loss of water and nutrients in vineyards [62]. Previous research also confirmed that bare ground was poor in constraining soil moisture [20]. The efficient use of soil water is transpiration, which regulates the stomatal state of the leaves and promotes the accumulation of nutrients by photosynthesis. The water loss from bare ground occurs through direct evaporation, which is a pure physical process. The higher the environmental temperature is, the greater the water loss. This situation may cause water stress and stomata closing environments and affect photosynthesis. Shandong Province has a sufficient annual rainfall, and the precipitation of the growing stages (Mar. to Sep.) was 855 mm and 1042 mm in 2019 and 2020, respectively, but the seasonal water distribution is uneven (Figure 1), and in that situation the risk of dryness/wetness events in the traditional management model exists [63,64]. In our experiment, there was no significant difference in CK, 2 cm and 6 cm straw mulching treatments in SBD. The 4 cm straw mulching treatment had the lowest SBD in 0–5 cm and the highest in 20–40 cm without changing the average SBD, indicating that a suitable straw thickness is more effective on water content in surface and bulk density in depth. Therefore, the 4 cm straw mulching treatment could best meet the needs of plant root growth and was suitable as a mulch thickness on soil [65].
As an open system with multiple actors in dynamic balance, we should improve the ability of vineyards to adapt to climate change and prevent agricultural pollution [17,66]. In this experiment, it was noted that straw mulching treatments had a significant effect on soil temperature, moisture, pH, TN, SOC, C/N, MWD and GMD compared with the CK (Figure 6 and Table 3), and soil SOC, C/N and moisture were increased with increasing thickness of maize straw mulching, while soil pH was decreased and then increased with the increasing thickness. The 4 cm straw mulching treatment had the greatest impact on the soil physical characteristics of SBD, which was suitable for maintaining MWD and GMD. The agronomic practices of straw mulching contribute to the rapid improvement of soil physicochemical properties and to the sustainability of viticulture and ensure soil quality and function [17,67].

5. Conclusions

Maize straw mulching had a synergistic effect on soil properties by increasing soil pH, SOC, C/N, MWD, GMD and SBD, but reduced TN and soil temperature in the organic vineyard. The suitable 4 cm maize straw represents a useful soil mulching thickness that provides beneficial services in the utilization of agricultural waste and is a suitable method both ecologically and environmentally. Its implementation could improve the soil health in vineyards. It is worth noting that the type and thickness of soil mulch should be adjusted according to the soil type, agricultural ecological environment and local agricultural waste in different scales before definitive conclusions can be drawn. Future research is needed to measure and compare the economic, social and environmental impacts of the sustainable management model with those of the traditional model.

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