A META-ANALYSIS OF THE EFFECTS ON SOIL QUALITY IN XINJIANG (CHINA) ORCHARDS AFTER GRASS CULTIVATION

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Abstract. To examine the responses of soil physicochemical properties, nutrients and microbial quantity to grass cultivation at different soil depths in orchards in Xinjiang (China), a database was established for meta-analysis based on collected related literature. The results showed that grass cultivation could improve soil physicochemical properties (e.g. water content, pH, bulk density, total porosity), soil nutrient content (e.g. organic matter, alkali hydrolyzed nitrogen, available phosphorus, available phosphorus, available potassium), and increase the number of soil microorganisms (e.g. fungi, actinomycetes), which indicated that grass cultivation had positive effects on soil in Xinjiang orchards.
Keywords: *grass cultivation in orchards, soil physicochemical properties, soil nutrients, soil microbial quantity, the response ratio, MetaWin*

Introduction

China is a large orchard country, but there are problems such as poor fruit quality, low yield and weak market competitiveness. Grass cultivation in orchards can improve the soil environment (Wei et al., 2021), and improve fruit quality and yield (Tu et al., 2021). It is a green management mode and is of great significance to promote the sustainable development of the forestry and fruit industry (Wei et al., 2021). In China, influenced by the traditional concept of clean tillage, coupled with the strict grass cultivation management requirements for farmers, the model is in the stage of the small-area application and has achieved good results in some areas such as Shandong, Henan, Anhui and other provinces. Many kinds of grasses can be used for orchard planting, most of which are Gramineae or Leguminosae plants, with different effects. Common species are alfalfa, hairy vetch, white clover and Lolium perenne (Chen et al., 2021; Li et al., 2022a; Otremba et al., 2021). There have been some studies on the effect of grass cultivation on soil quality in orchards. Wei et al. (2021) indicated that Stylo grass cultivation in pomegranate orchards could promote soil respiration and increase the soil water content. The study by Li et al. (2022b) showed that grass cultivation in apple orchards could increase soil organic matter, total nitrogen, available nitrogen and available nitrogen content. The study by Qin et al. (2022) showed that grass cultivation in orchards could prevent soil erosion, improve soil quality and increase nutrient content.

Xinjiang is located in the northwest of China, 73°40′ ~ 96°23′ E and 34°22′~49°11′ N, belonging to the desert climate. Different from other regions in China, the ecology in this region is fragile, mainly saline-alkali soil with low organic matter content. Salinization and barrenness are common (Cao et al., 2022). Based on a meta-analysis, this study was conducted by collecting data on grass cultivation in Xinjiang orchards

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from China National Knowledge Infrastructure (CNKI), to quantify the effects of grass cultivation on soil physicochemical properties, soil nutrients and soil microbial quantity, to provide a theoretical basis for the specific effects of grass cultivation on soil quality in Xinjiang orchards.

Data source and methodology

Data collection

The present study aimed to investigate the soil characteristics of orchards in Xinjiang, China, based on a meta-analysis. The data were obtained from CNKI, which contains the published literature on experiments on grass cultivation in orchards conducted in Xinjiang, China, up to December 2021. The search expressions in CNKI were SU = ‘Xinjiang’ and SU = ‘orchard’ and (SU % ‘green manure’ + ‘grass’).

To eliminate the unqualified literature, after the initial screening through the abstract reading, the literature were screened based on the following criteria:(1) the experiment was conducted in an orchard in Xinjiang, China; (2) the same experiment contained both experimental and control groups (grass cultivation group and clean tillage group), and other management measures were the same; (3) the experiment data contained at least one of soil physicochemical properties (water content, pH, bulk weight, total porosity), soil nutrients (organic matter, alkaline nitrogen, fast-acting phosphorus, fast-acting potassium), soil microbial population (fungi, actinomycetes).

After the screening, 28 pieces of literature were finally entered into the database, including 179 groups of orchard soil water content data, 79 groups of orchard soil pH data, 25 groups of orchard soil total porosity data, 100 groups of orchard soil bulk weight data, 102 groups of orchard soil organic matter content data, 104 groups of orchard soil alkaline nitrogen content data, 108 groups of orchard soil fast-acting phosphorus content data, 102 groups of orchard soil fast-acting potassium content data, 44 groups of orchard soil fungal population data, and 12 groups of orchard soil actinomycetes population data.

Methods

The data in this study were obtained from the retrieved literature. When establishing the database, if the data in the original literature were represented graphically, they were extracted into data form using GetData Graph Digitizer software (Wang et al., 2022b; Zhang et al., 2022). To smoothly integrate multiple research experiments, the natural logarithm of the response ratio (RR) was used to express the effects of the grass cultivation measures on the orchard soil (*Eq. 1*), which we called the effect size (Ma et al., 2022; Wang et al., 2022a).

$$\ln RR = X_e/X_c \qquad \text{(Eq.1)}$$

In the formula, X_e is the mean value of the experiment group, and X_c is the mean value of the control group. The effect size (lnRR) variance (S_d) is calculated as *Equation 2*:

$$S_d = \frac{S_e^2}{N_e X_e^2} + \frac{S_c^2}{N_c X_c^2} \qquad \text{(Eq.2)}$$

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In the formula, S_c is the standard deviation of the control group, S_e is the standard deviation of the experimental group, N_c is the number of samples in the control group, and N_e is the number of samples in the experiment group.

If the data provided in the literature are standard errors (S_e), the conversion is performed by *Equation 3*:

$$S_d = S_e^{\sqrt{n}} \quad \text{(Eq.3)}$$

where n is the number of experiment repetitions.

For ease of understanding and description, the m value (percentage) obtained through the effect sizes obtained above by *Equation 4* was used as the final effect size to characterize the changes in soil physicochemical properties, nutrient content, etc.

$$m = (\exp(\ln RR)-1)\times 100\% \quad \text{(Eq.4)}$$

MetaWin software was used in this study, which provides two hypothetical models (i.e., a fixed-effects model and a mixed-effects model). The former assumes that the integrated research items share the same true effect size, and the actual measured effect size is different due to random sampling, while the latter assumes that the integrated items have different true sizes, and the difference in the measured effect size is due to the two factors (that is, due to different effect sizes of each item and random sampling).

A mixed model was chosen in this meta-analysis to ensure that the results were relatively reliable. The integrated effect size and 95% confidence intervals (95% CI) of each experimental item were calculated by entering the mean value, sample size, and standard deviation of the control group and the experimental group in the database (Ma et al., 2023). If the confidence interval contains 0, it means that the grass cultivation has no significant effect on the soil properties; if the confidence interval is all greater than 0, it means that the grass cultivation has a significant positive effect on the soil properties; if the confidence interval is all less than 0, it means that the grass cultivation has a significant positive effect on the soil properties (Wang et al., 2022b; Zhang et al., 2022).

Results

Effects of grass cultivation on soil physicochemical properties

The meta-analysis results showed that grass cultivation could increase the soil water content and total porosity, and decrease the soil pH and bulk density. The specific effects were as shown in *Figures 1, 2, 3* and *4*.

In the figures, bars with error bars denote the overall mean response ratio and 95% CI, respectively. The 95% CI that did not go across the zero line meant a significant difference between treatment and control. The values in parentheses were independent sample sizes. The number in brackets behind the different confidence intervals indicates the number of applied input data (the same below).

(1) Effect of grass cultivation on soil water content. As shown in *Figure 1*, grass cultivation could increase the soil water content at different soil depths. The water content at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm, 60~80 cm, and 80~100 cm increased by 14.11%,14.99%, 8.53%, 5.68% and 11.58%, respectively. The confidence intervals of the effect on the water content of each soil layer were all completely located

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on the right side of the 0 line, indicating that grass cultivation management measures had a significant effect on increasing the soil water content compared with clean tillage, and the order of the effect from high to low was 20~40 cm > 0~20 cm > 40~60 cm > 80~100 cm > 60~80 cm.

(2) Effect of grass cultivation on soil pH. The Xinjiang region is mostly saline-alkali and barren soils, and excessive alkalinity is not conducive to fruit tree growth. As shown in *Figure 2*, grass cultivation could decrease the soil pH at different soil depths. The pH at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm and 60~80 cm decreased by 2.22%, 2.36%, 1.0% and 1.49%, respectively. The confidence intervals of the effect on pH value of each soil layer were all completely on the left side of the 0 line, indicating that grass cultivation management measures had a significant effect on decreasing soil pH value compared with clean tillage, and the order of the effect from high to low was 20~40 cm > 0~20 cm > 60~80 cm > 40~60 cm.

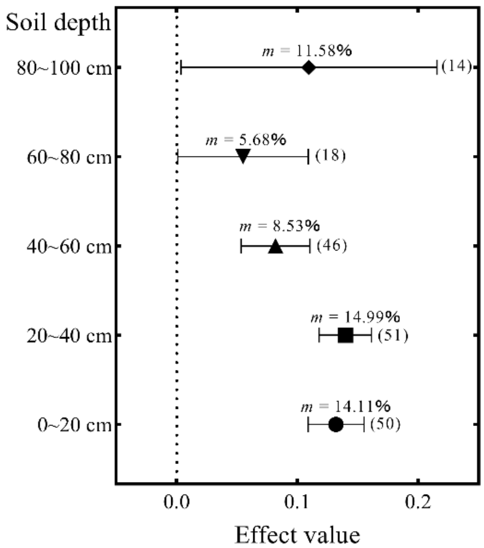

***Figure 1.** Effect of grass cultivation on soil water content at different soil depths*

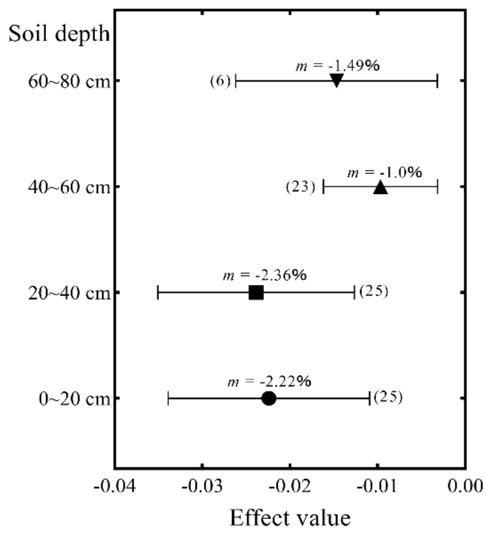

***Figure 2.** Effect of grass cultivation on soil pH value at different soil depths*

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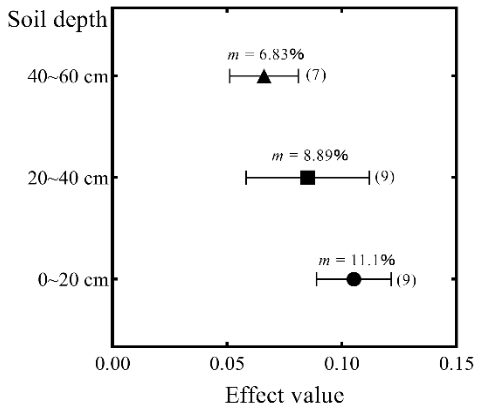

Figure 3. *Effect of grass cultivation on soil total porosity at different soil depths*

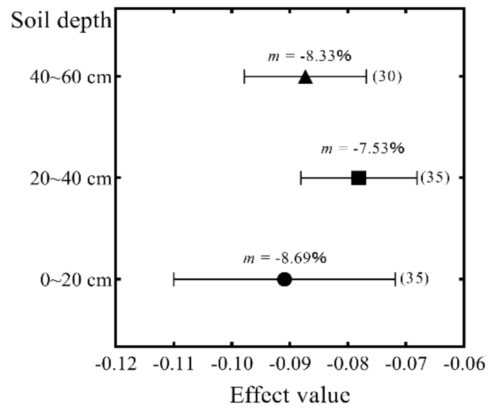

Figure 4. *Effect of grass cultivation on soil bulk density at different soil depths*

(3) Effect of grass cultivation on the soil total porosity. As shown in *Figure 3*, grass cultivation could increase the soil total porosity at different soil depths. The total porosity at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm and 60~80 cm increased by 11.1%, 8.89% and 6.83%, respectively. The confidence intervals of the effect on the soil total porosity of each soil layer were all completely on the right side of the 0 line, indicating that grass cultivation management measures had a significant effect on improving the soil total porosity compared with clean tillage, and the order of the effect from high to low was 0~20 cm > 20~40 cm > 60~80 cm > 40~60 cm.

(4) Effect of grass cultivation on soil bulk density. Affected by the application of chemical fertilizers all year round, the soil in Xinjiang orchards has been gradually hardened, thus increasing the bulk density, which is not conducive to fruit tree growth. As shown in *Figure 4*, grass cultivation could decrease the bulk density at different soil depths. The bulk density at the soil depths of 0~20 cm, 20~40 cm and 40~60 cm decreased by 8.69%, 7.53% and 8.33%, respectively. The confidence intervals of the effect on the bulk density of each soil layer were all completely on the left side of the 0 line, indicating that the grass cultivation management measures had a significant effect on decreasing the bulk density compared with clean tillage, and the order of the effect from high to low was 20~40 cm > 0~20 cm > 40~60 cm > 80~100 cm > 60~80 cm.

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Effects of grass cultivation on soil nutrients

The meta-analysis results showed that grass cultivation could improve the organic matter content, soil alkaline nitrogen, fast-acting phosphorus, fast-acting potassium, total nitrogen, total phosphorus and total potassium content of orchards in Xinjiang, and the specific effects were as shown in *Figures 5*, *6*, *7* and *8*.

(1) Effect of grass cultivation on soil organic matter content at different soil depths. As shown in *Figure 5*, the soil organic matter content at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm and 60~80 cm increased by 19.7%, 30.25%, 25.22% and 27.55%, respectively. The confidence intervals of the effect on the soil organic matter content of each soil layer were all completely on the right side of the 0 line, indicating that the grass cultivation management measures had a significant effect on increasing the soil organic matter content compared with clean tillage, and the order of the effect from high to low was 20~40 cm > 60~80 cm > 40~60 cm > 0~20 cm.

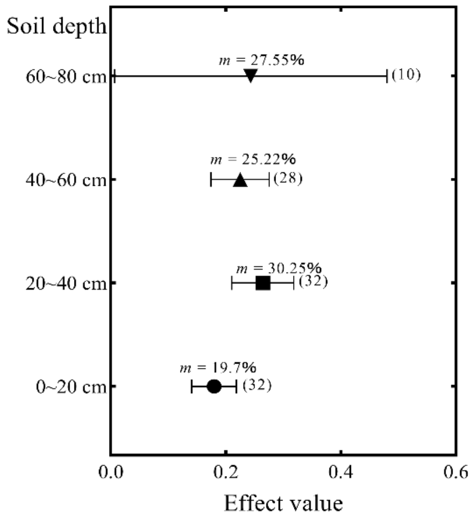

Figure 5. *Effect of grass cultivation on soil organic matter content at different soil depths*

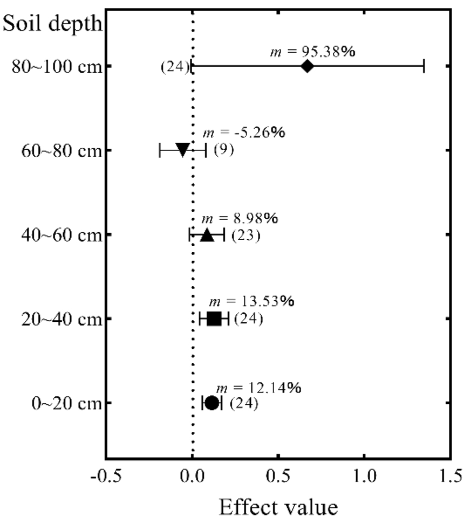

Figure 6. *Effect of grass cultivation on soil alkaline dissolved nitrogen content at different soil depths*

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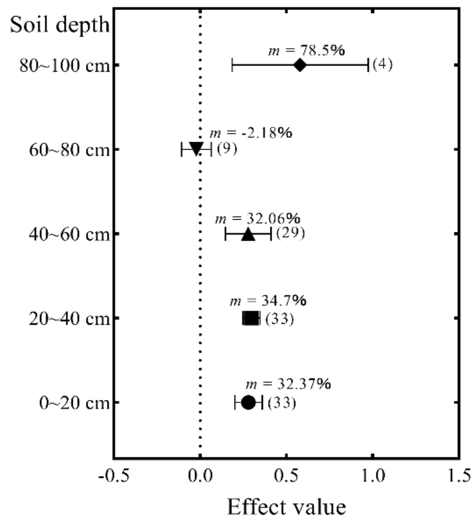

Figure 7. *Effect of grass cultivation on soil available phosphorus content at different soil depths*

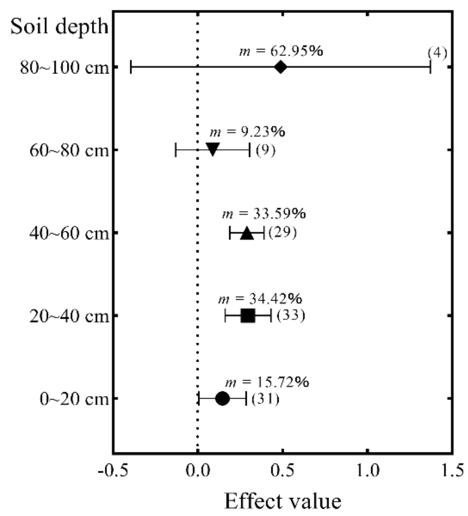

Figure 8. *Effect of grass cultivation on soil available potassium content at different soil depths*

(2) Effect of grass cultivation on soil alkaline dissolved nitrogen content at different soil depths. As shown in *Figure 6*, the soil alkaline dissolved nitrogen content at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm and 80~100 cm increased by 12.14%, 13.53%, 8.98% and 95.38%, respectively, while at the soil depths of 60~80 cm decreased by 5.26%. The confidence intervals of 0~20 cm and 20~40 cm soil layers were located to the right of the 0 line, indicating that grass cultivation could significantly increase the alkaline hydrolysis N content of these two soil layers compared with clean tillage, while the effect on 40~60 cm and 80~100 cm soil layers were not significant, and the effect on 60~80 cm soil layer had a negative trend, but not significant.

(3) Effect of grass cultivation on soil available phosphorus content at different soil depths. As shown in *Figure 7*, the soil alkaline dissolved nitrogen content at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm and 80~100 cm increased by 32.37%, 34.7%, 32.06% and 78.5%, respectively, while at the soil depths of 60~80 cm decreased by 2.18%. The confidence intervals of 0~20 cm, 20~40 cm, 40~60 cm, and 80~100 cm soil

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layers were located to the right of the 0 line, indicating that management measures had a significant effect on increasing the available potassium content and had a negative effect on the 60-80 cm soil layer, but not significant.

(4) Effect of grass cultivation on soil available potassium content at different soil depths. As shown in *Figure 8*, grass cultivation could increase the soil available potassium content at different soil depths. The soil available potassium content at the soil depths of 0~20 cm, 20~40 cm, 40~60 cm, 60~80 cm and 80~100 cm increased by 15.72%, 34.42% and 33.59%, 9.23% and 62.95%, respectively. The confidence intervals of the effect on the soil available potassium content of 0~20 cm, 20~40 cm and 40~60 cm layer were completely on the right side of the 0 line, indicating that the grass cultivation management measures had a significant effect on increasing the soil available potassium content in this soil depth range, and the order of the effect from high to low was 20~40 cm > 40~60 cm > 0~20 cm. The confidence interval of 0~20 cm includes the 0 line, indicating that the effect is not significant at that soil depth.

Effects of grasses cultivation on soil microbial quantity

The meta-analysis results showed that grass cultivation could increase soil microbial quantity such as fungi and actinomycetes, and the specific effects were as shown in *Figures 9* and *10*.

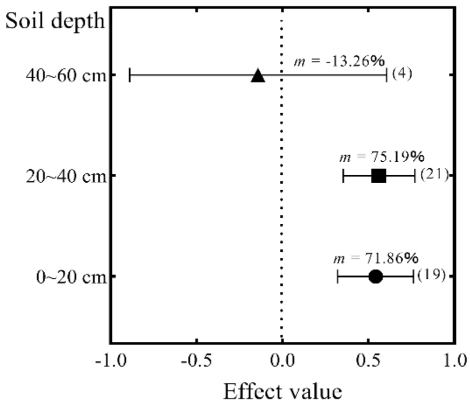

Figure 9. *Effect of grass cultivation on the number of soil fungi at different soil depths*

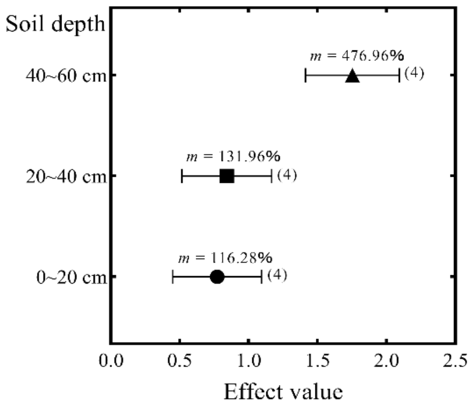

Figure 10. *Effect of grass cultivation on the number of soil actinomycetes at different soil depths*

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(1) Effect of grass cultivation on the number of soil fungi at different soil depths. As shown in *Figure 9*, grass cultivation could increase the number of fungi in the soil layers of 0~20 cm and 20~40 cm, which increased by 71.86% and 75.19%, respectively. Their confidence intervals were completely on the right side of the 0 line, indicating that grass cultivation management measures had a significant effect on increasing the number of fungi in those soil layers. The number of fungi in the 40~60 cm soil layer decreased by 13.26%, with the confidence interval containing a 0 line, indicating that the negative effect of grass cultivation on it was not significant.

(2) Effect of grass cultivation on the number of soil actinomycetes at different soil depths. As shown in *Figure 10*, grass cultivation could increase the number of soil actinomycetes at different soil depths. The number of soil actinomycetes at the soil depths of 0~20 cm, 20~40 cm and 40~60 cm increased by 116.28%, 131.96% and 476.96%, respectively. The confidence intervals of the effect on the number of soil actinomycetes of each soil layer were all completely located on the right side of the 0 line, indicating that grass cultivation management measures had a significant effect on increasing the number of soil actinomycetes compared with clean tillage, and the order of the effect from high to low was 40~60 cm > 20~40 cm > 0~20 cm.

Discussion

The meta-analysis showed that grass cultivation could improve soil quality in Xinjiang orchards, but the effects varied at different soil depths of soil layers. 0~20 cm and 20~40 cm had more significant effects as a whole, which may be related to the fact that most of the roots of grasses grow and move in this range. However, there were opposite results for individual indicators, such as the number of fungi and actinomycetes, which may be caused by the small sample size and insignificant statistical significance due to the small number of relevant studies currently conducted.

(1) Grass cultivation can improve soil physicochemical properties (Xiao et al., 2022). Grass can alleviate the radiation effect of the sun on the soil, increase the albedo, and then reduce the surface temperature, and grass cultivation can reduce the wind speed on the surface, reduce evaporation and soil loss of the soil surface (Ahmad et al., 2021; Zheng et al., 2021). The growth and interpolation of grassroots are conducive to the formation of soil pores, which improves the soil structure, decreases the soil bulk density, increases the soil total porosity (D’Amours et al., 2021), enhances the water holding capacity of the soil and thus increases the soil water content. As an important index to evaluate the physical properties of soil, soil bulk density can reflect the degree of soil maturation, and the reduction of soil bulk density also reflects the improvement of soil structure, air permeability and water permeability (Tu et al., 2021). Meanwhile, grass cultivation can decrease soil pH and provide a good acid-base environment for fruit trees. In conclusion, the improvement of the soil physicochemical properties of orchards by grass cultivation is conducive to the root growth and the nutrient absorption of fruit trees, which is significant for orchards in Xinjiang, where there is a serious water shortage and poor soil quality.

(2) Grass cultivation can increase soil nutrient content and microbial quantity. Organic residues such as grass twigs and secretions will be continuously input into the orchard ecosystem, and will continue to rot and mineralize in the soil, which will increase soil nutrients (Zhou et al., 2021). After the grass cultivation, the root system expands downwards and around, the organic residues in the soil root system and above-

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ground parts increase, and a large amount of litter and rhizosphere sediments accumulate to provide sufficient substrates for microorganisms (Wei et al., 2022; Xiao et al., 2022). Therefore, the diversity, activity, community structure and function of soil microorganisms can be significantly improved, thereby maturing the soil, changing the composition of soil particles, decreasing soil bulk density, and helping to improve soil porosity and water holding capacity (Li et al., 2022b; Wan et al., 2021). Meanwhile, the increase in the number of microorganisms contributes to the decomposition of organic matter, nutrient circulation and energy flow, and helps to increase soil nutrients including organic matter, alkali-hydrolyzed nitrogen, available phosphorus, and available potassium (Hu et al., 2022; Sokol et al., 2022). In addition, leguminous forage can fix nitrogen by rhizobia, so it has a stronger nitrogen fixation effect (Liu et al., 2022).

Conclusions

This study analyzed the effects of grass cultivation on soil quality at different soil depths for the orchard environment in Xinjiang based on a meta-analysis, and drew a forest map, indicating that grass cultivation could improve soil physicochemical properties in orchards 0~40 cm, increase soil nutrients and the number of soil microorganisms. There were relatively few research pieces of literature on the effects of some soil layers, and the statistical significance was not obvious. In a later study, we can focus on experiments and analysis in this field. At the same time, we can also wait for a certain number of pieces of literature to accumulate and conduct a meta-analysis again, for providing some theoretical and technical support for orchard soil improvement, small ecological environment improvement and even farmers' income increase. In addition, the existing literature focuses on the study of grass cultivation on the soil environment in orchards, but there are relatively few studies on the effects of fruit tree growth and fruit quality. In the latter study, relevant experiments on the coupling effect of grass-soil-fruit quality can be considered to further clarify the mechanism by which grass cultivation in the orchard can improve fruit quality.

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