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Experiment and meta-analysis on the effects of grass cultivation in the orchard on fruit yield and quality

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Abstract

Grass cultivation in orchard technology has been implemented in some parts of the world, and different regions have different effects on fruits due to their different geographical environments. In this paper, Xinjiang, China, which has a temperate continental climate, is selected as the research area. Through orchard experiments and meta-analysis, the influence of grass cultivation on orchards in this area is studied. Experiments and the meta-analysis both showed that the single fruit weight, yield per plant and fruit quality were improved after grass cultivation in the orchards. This indicates that grass cultivation is of great significance to orchards in Xinjiang.

Keywords: grass cultivation in orchard; meta-analysis; fruit quality and yield.

Practical Application: Exploring the effects of grasses cultivation in the orchards on fruit yield and quality by means of experiments and meta-analysis can provide a reference for the orchard management.

1 Introduction

Grass cultivation in the orchards is a kind of soil management technology for planting specific crops between rows or covering the whole orchard. It has the functions of improving soil structure, increasing soil nutrients, enriching population tribes, promoting the growth and development of fruit trees, and improving fruit yield and quality(Chao et al., 2021; Li et al., 2021; Zhao & Chen, 2022). This technology has been widely promoted in Europe and the United States. In China, due to the influence of traditional clean tillage concepts, lack of supporting machinery and tools, and complex management, fruit farmers are not enthusiastic about using this technology (Niu et al., 2021; Wang et al., 2022c). In recent years, research on this technology has gradually increased.

Liu et al. (2021) showed that grass cultivation in orchards can increase the chlorophyll content and specific leaf weight of mango leaves, and improve the soluble solid content (SSC) of mango fruits. Among them, planting milkvetch also reduces the titratable acid content of mango and increases the weight of mango single fruit. Bai et al. (2021) showed that natural grasses cultivation can increase the calcium content of apple fruits, reduce the nitrogen calcium ratio, phosphorus calcium ratio and potassium calcium ratio, reduce the incidence of calcium deficiency symptoms, increase the fruit color area, fruit hardness and SSC, and then improve the fruit quality. Xiao et al. (2022) showed that artificial planting of ryegrass and white clover can not only improve the supply of soil nitrogen, phosphorus and potassium nutrients in orange orchards, but also significantly improve the richness and diversity of microbial communities, optimize the structure of soil bacterial and fungal communities, and promote the sustainable development of the tangerine industry.

Meta-analysis is a statistical method used to compare and synthesize the results of studies on the same scientific question (Ma et al., 2022; Tang et al., 2022a). Whether the conclusion is meaningful or not depends on the quality of the included studies. Compared with a single study, by integrating all relevant studies, the effect of certain factors can be estimated more accurately, and it is helpful to explore the consistency of evidence among studies and the differences between studies (Wang et al., 2022a). When the results of multiple studies are inconsistent or have no statistical significance, Meta-analysis can be used to obtain statistical analysis results that are close to the real situation (Wang et al., 2022b).

This study aims to analyze the effects of grass cultivation in the orchards on fruit yield and quality based on experiments and meta-analysis. We take Korla pear as the research object, and analyze the effects of grass cultivation in the orchards on the quality and yield of Korla pear fruit based on orchard experiments. At the same time, for this region (Xinjiang, China), we collect and extract effective data from published papers in the past 20 years (2000-2021) on the effects of grass cultivation in the orchards on fruit yield (single fruit quality, single plant yield, mu yield, etc.), fruit external quality (hardness, fruit shape coefficient), fruit internal quality (titratable acid, soluble solid, soluble sugar, vitamin C, sugar acid ratio), and systematically analyze the effects of grass cultivation in the orchards on the above response variables based on meta-analysis, to provide certain theoretical support for clarifying the effects law of grass cultivation in the orchards and the rational use of this technology.

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2 Study on the effects of grass cultivation in orchard on fruit yield and quality

2.1 Materials and methods

The study area is located in the pear garden demonstration base of the 12th regiment in Alar City, Xinjiang Uygur Autonomous Region (40°28’ N, 81°26’ E). It belongs to a typical continental warm temperate dry climate with a long sunshine time, an average annual temperature of 10.7 °C, a frost-free period of 220 days, annual sunshine of more than 2900 hours, and tree age of 5 years. The soil type is sandy loam, with organic matter content of 11.46/kg, available nitrogen of 23.71 mg/kg, available phosphorus of 18.79 mg/kg, available potassium of 116 mg/kg and pH of 7.7. The experiment was conducted in Korla pear orchard from 2020 to 2021, with a plant row spacing of 4.5 m × 7 m, sown in March 2021, and relevant data were collected in September. A single factor complete random design was adopted, with two treatments, namely, clean tillage and grass cultivation in a pear orchard.

Measurement items: (1) fruit quality and yield per plant. 20 pears were picked and the single fruit mass of Korla pear was weighed with an electronic scale based on the five-point sampling method; (2) fruit external quality, including fruit firmness and fruit shape index. The longitudinal diameter and transverse diameter of fruits obtained were measured with a vernier caliper, and the fruit shape index was expressed by the ratio of the longitudinal diameter and transverse diameter of fruits. The hardness of pear fruit with and without skin was measured by a fruit hardness tester; (3) determination of the internal quality of fruit, including soluble solid content, soluble sugar content, titratable acid content and vitamin C content. The content of soluble solid was determined by a hand-held sugar meter, the content of soluble sugar was determined by anthrone colorimetry, the content of vitamin C was determined by 2,6-dichloroindophenol titration, and the content of titratable acid was determined by NaOH titration. Repeat the above measurement 3 times each time and take the average value.

2.2 Results and analysis

(1) Effect of grass cultivation on fruit yield. As shown in Table 1, after grass cultivation in the orchard, the quality of single fruit and the yield of the single plant have been improved to a certain extent, with an increase of 0.92% and 7.70% respectively;

(2) Effect of grass cultivation on external quality of fruit. As shown in Table 2, after grass cultivation in the orchard, the longitudinal diameter and transverse diameter of Korla pear increased slightly by 0.35% and 0.18% respectively, and the fruit shape index also increased slightly. The hardness decreased by 8.02%;

(3) Effect of grass cultivation on internal quality of fruit. As shown in Table 3, after grass cultivation in the orchard, the soluble solid content, soluble sugar content and vitamin C content in Korla pear fruit increased by 8.20%, 0.91% and 4.35% respectively, but the effect on titratable acid content was not obvious.

Table 1. Comparison of fruit yield between clean tillage and grass cultivation in the orchard.

Item	Clean tillage	Grass cultivation	Increase
Single fruit weight/g	101.46 ± 3.11	102.39 ± 2.97	0.92%
Yield per plant/ kg	21.16 ± 0.94	22.79 ± 1.27	7.70%

Table 2. Comparison of fruit external quality between clean tillage and grass cultivation in the orchard.

Item	Clean tillage	Grass cultivation	Increase
Longitudinal diameter / mm	63.15 ± 0.91	63.37 ± 1.06	0.35%
Transverse diameter /mm	55.71 ± 0.73	55.81 ± 0.87	0.18%
Fruit shape index	1.13 ± 0.017	1.14 ± 0.021	0.88%
Fruit firmness/ $kg.cm^{-2}$	9.72 ± 0.53	8.94 ± 0.41	-8.02%

Table 3. Comparison of fruit internal quality between clean tillage and grass cultivation in the orchard.

Item	Clean tillage	Grass cultivation	Increase
Soluble sugar content/%	10.92 ± 0.58	11.02 ± 0.67	0.91%
Titratable acid content/%	0.057 ± 0.0043	0.057 ± 0.0067	0%
Vitamin C content/ ($mg{\cdot}g^{-1}$)	0.23 ± 0.055	0.24 ± 0.059	4.35%
Soluble solid content/%	13.62 ± 0.037	14.74 ± 0.39	8.20%

Grass cultivation in the orchard had some effects on the yield and quality of Korla pear, but the overall effect was not obvious. This may be related to the short implementation time of the grass cultivation mode. Through exchanges and investigations with local fruit farmers, it is known that the effect of grass cultivation in the orchards is slow, and it usually takes at least 3 years to have visible results. Fruit farmers are eager for high yields, and are more willing to use the clean tillage + chemical fertilizer method, which is effective, which is also one of the main reasons for the difficulty in popularizing this orchard management technology. In the later implementation of this technology, the combined effect of grass cultivation and chemical or organic fertilizers can be considered to improve the comprehensive benefits of orchards.

3 Meta-analysis of the effects of grass cultivation in orchards on fruit yield and quality

3.1 Materials and methods

Data sources

This study mainly focused on the Xinjiang region in China. The data was retrieved based on China National Knowledge Infrastructure (CNKI), and the papers on grass cultivation experiments in Xinjiang orchards, which were published as of December 2021, were obtained. The main subject headings of the search were “Xinjiang/Southern Xinjiang/Northern Xinjiang” and "grass cultivation in orchard/green manure in the orchard", and then the papers were further screened and a Meta-analysis database was established based on the following criteria: (1) the experimental site is an orchard in Xinjiang, China; (2) the same experiment included the experimental group and the control group (that is, the grass cultivation group and the clean tillage group), and other orchard management measures were consistent; (3) the experimental data includes at least one of the fruit quality of fruit trees, the yield per plant, the yield per mu, the content of soluble solids, the content of soluble sugar, the content of titratable acid, the ratio of sugar to acid, the content of vitamin C, and the fruit firmness. After screening, a total of 28 papers were finally obtained, including 42 sets of fruit quality data, 5 sets of per-mu yield data, 7 sets of yield data per plant, 38 sets of fruit firmness data, 33 sets of fruit shape index data, 23 sets of titratable acid content data, 40 sets of vitamin C content data, 39 sets of soluble sugar content data, 41 sets of soluble solid content data, and 10 sets of sugar-acid ratio data.

Data calculation and statistical analysis

To make the results of the various studies comparable, the effect size of each independent study was calculated in the meta-analysis (Silva et al., 2022). In this study, the logarithm of the response ratio (*RR*) was used as the effect size to measure the effect of the grass cultivation treatment on the above response variables. The specific calculation method of effect size is shown in Formula 1 (Namin et al., 2021; Rothrock et al., 2022).

$$E = \ln RR = \ln\left(\frac{X_t}{X_c}\right) = lnX_t - linX_c \quad (1)$$

where, X_t and X_C are the average values of response variables such as single fruit quality, yield per mu and yield per plant corresponding to the grass cultivation group and control group respectively. If $E > 0$, grass cultivation in orchards has a positive effect on response variables; if $E = 0$, grass cultivation in orchards has no effect on response variables; if $E < 0$, grass cultivation has a negative effect on the response variable. Assuming that X_t and X_c are normally distributed, and $X_c \neq 0$, ln*RR* is also normally distributed, and its variance is calculated according to Formula 2 (Grgic et al., 2022; Shephard et al., 2022).

$$V_{\ln RR} = \frac{S_t^2}{N_t X_t^2} + \frac{S_c^2}{N_c X_c^2} \quad (2)$$

In the formula, S_t, S_c, X_t, X_c, N_t, and N_c are the standard deviation, mean, and sample size of the treatment group and the control group.

There are two hypothetical models in meta-analysis: the fixed-effects model and the random-effects model. The fixed-effects model assumes that all studies have only one true combined effect size, and random sampling will result in different actual measured effect sizes; the random-effects model assumes that the true effect sizes between studies are different, and there is inherent randomness in the variation of effect values. The orchard experiments included in this study came from different regions, different experimental years, different fruit trees, and different soil qualities in Xinjiang, thus all independent studies cannot share a combined effect size. To improve the accuracy of the overall effect size, a random effect model was used to calculate the effect size. In the collected papers, some data are represented in the form of images, and the images can be digitized with the help of GetData software (Najafi et al., 2022; Zhou et al., 2021). If the data provided in the papers is the standard error (*SE*), the standard deviation (*SD*) can be calculated by the Formula 3 to convert.

$$SD = SE^{\sqrt{n}} \quad (3)$$

The calculation work of this study is based on Metawin 2.0 software, and the response ratio (*RR*) and 95% confidence interval (CI) of each experimental group and the control group were obtained to present the effect and significance level of grass cultivation in orchards. After that, forest plots were drawn in GraphPad Prism 9.0 software based on the calculated data. To facilitate understanding and description, based on the effect size obtained according to Formula 2, the effect size is further processed by Formula 4 to obtain the final effect size of the effect of grass cultivation in orchards on fruit yield and quality. In each group of data, if the 95% CI does not coincide with the zero line, the treatment is considered to have a significant effect on the target variable; if the 95% CI is on the left side of the zero line, the treatment is considered to have a negative effect on the target variable; if the 95% CI is on the right side of the zero line, the treatment is considered to have a positive effect on the target variable; if the 95% confidence intervals of the data in each group do not overlap, it is considered that there is a significant difference between groups (Zhang et al., 2022; Zhao et al., 2022).

$$m = exp\left(lnRR\right) - 1) \times 100\% \quad (4)$$

3.2 Results and analysis

(1) The effect of grass cultivation on fruit yield (Figure 1). The results of the meta-analysis showed that grass cultivation in orchards could improve fruit quality, yield per mu and yield per plant in Xinjiang orchards by 5.8%, 17.14%, and 37.75%, respectively. Among them, the 95% CI used to describe the effect of grass cultivation on the quality of single fruit and yield per plant are all located on the right side of the zero line, indicating that it has a significant positive effect on the improvement of both. The 95% CI used to describe the effect of grass cultivation on the yield per mu includes the zero line, indicating that the effect of grass cultivation on it is insignificant;

(2) The effect of grass cultivation on the external quality of fruit (Figure 2). The results of the meta-analysis showed that grass cultivation in orchards can reduce fruit firmness and slightly increase the fruit shape index, which decreased and increased by 2.24% and 0.16%, respectively. Among them, the 95% CI used to describe the effect of grass cultivation on the fruit firmness are all located on the left side of the zero line, indicating that the reduction is significant, while the 95% CI used

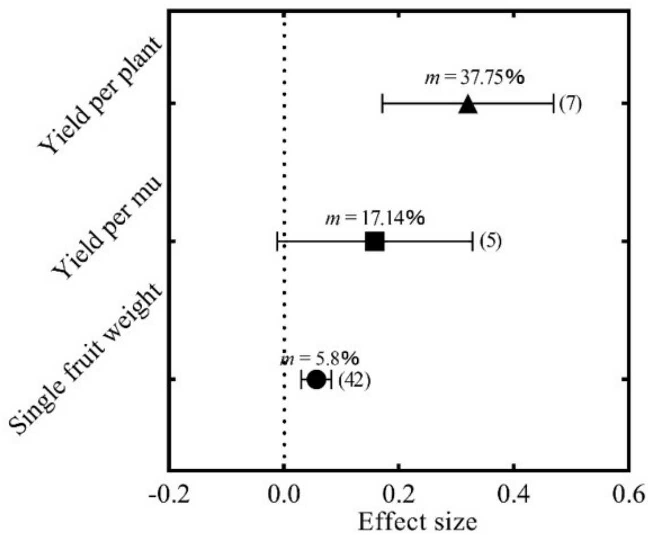

Figure 1. The effect of grass cultivation on fruit yield.

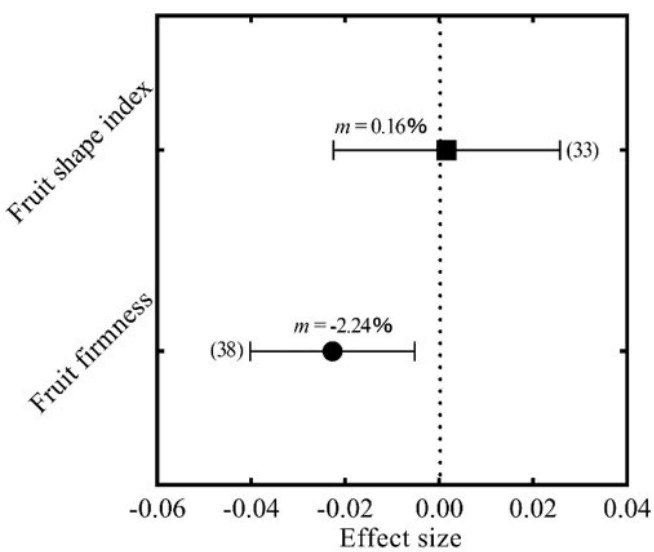

Figure 2. The effect of grass cultivation on the external quality of fruit.

to describe the effect of grass cultivation on fruit shape index includes the zero line, indicating that the effect of grass cultivation on the fruit shape index is insignificant;

(3) The effect of grass cultivation on the internal quality of fruit (Figure 3). The results of the meta-analysis showed that grass cultivation in orchards can improve titratable acid content, vitamin C content, soluble sugar content, soluble solid content and sugar-acid ratio, by 1.21%, 4.38%, 10.82%, 1.38%, and 35.53%, respectively. Among them, the 95% CI used to describe the effect of grass cultivation on the soluble solid content and titratable acid content includes the zero line, indicating that the effect is insignificant, and the rest are located on the right side of the zero line, indicating that the effect is significant.

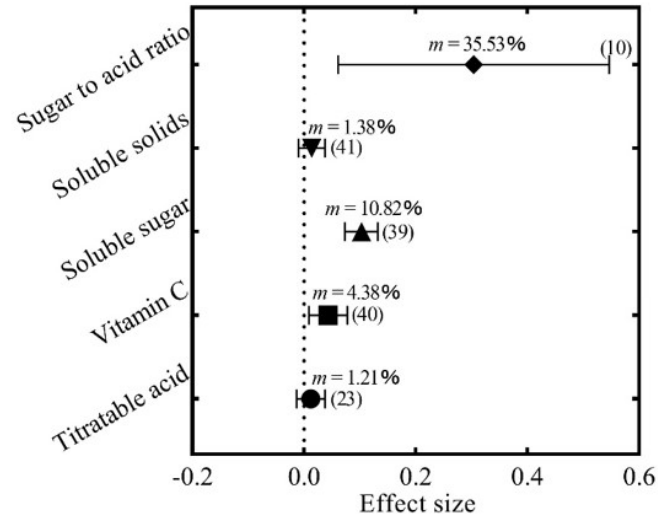

Figure 3. The effect of grass cultivation on internal quality of fruit.

4 Discussion

The reason why the fruit yield and the quality of the fruit can be improved after grass cultivation in orchards has a great relationship with the benign effects of grass cultivation on the orchard environment.

(1) Grass cultivation in orchards can reduce soil bulk density, increase soil porosity, and improve orchard soil structure (Webber et al., 2022). This is because the soil particles are entangled by the roots of the grass crops, and the secretions released by the grassroots will cause the soil particles to bond and rearrange, resulting in changes in the soil structure, promoting the formation of soil aggregates, and improving the aeration and water permeability of the soil (Meza et al., 2022);

(2) Grass cultivation in orchards has a water retention effect (Tu et al., 2021). Firstly, the grass has an interception effect on rainfall and reduces surface runoff. Secondly, after grass cultivation, the total soil porosity increases and the soil bulk density decreases under the action of the grass root system, thereby increasing the water storage capacity of the soil (Qin et al., 2022);

(3) Grass cultivation can increase the total amount of microorganisms and improve soil fertility(Sun et al., 2022). The grass exudates and the residual branch decomposition promote the increase of organic matter, create a suitable environment for the growth and reproduction of microorganisms, increase the number of microorganisms, and further increases the activity of soil enzymes, which is beneficial for soil microorganisms to participate in nutrient cycling, organic matter decomposition and energy flow (Li et al., 2022; Qin et al., 2022);

(4) Grass cultivation in orchards has the function of adjusting the soil temperature. The large-scale changes in the external ambient temperature can be blocked by

the grass, thereby reducing the temperature fluctuation of the soil surface, which is conducive to the growth of fruit tree roots (Hao et al., 2021; Tang et al., 2022b).

In addition, some indicators did not change significantly in the meta-analysis, which may be related to the slow effect of grass cultivation. The effects of chemical fertilizer, organic fertilizer and grass cultivation on fruit quality and yield deserve further study in the future. Due to the small number of studies on some indicators (yield per plant, yield per mu, etc.) in the meta-analysis, the statistical significance of some indicators is not good. On the one hand, we can focus on doing some related study on this indicator, on the other hand, further meta-analysis can be carried out when the number of studies is sufficient.

5 Conclusion

Through the orchard experiment and Meta-analysis, this paper shows that grass cultivation in orchards can improve the yield and quality of fruit to a certain extent, which provides certain theoretical support for the development of grass cultivation technology. However, in the Meta-analysis, the effects of grass cultivation on some quality indicators were not significant, which may be related to the insufficient number of experiments in this area or the slow effect of grass cultivation. A multi-year follow-up study of the effects of grass cultivation techniques may be considered in the future.

Ethical approval

This paper does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare no conflict of interest.

Availability of data and materia

The data in this paper are obtained from CNKI and experiments.

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