




Article

Effect of Intercropping on Fruit Yield and Financial Benefits of *Rosa roxburghii* Tratt Orchard in Southwest China

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Abstract: The practice of intercropping in *Rosa roxburghii* Tratt orchards holds potential for enhancing fruit yield and financial benefits, yet remains insufficiently explored. To address this, we delved into the effects of intercropping on fruit yield and financial viability of *R. roxburghii* orchards in Longli County, southern China. Orchards of varying ages (4 years old and 5 years old; 7 years old and 8 years old) were subjected to different treatments: (i) *Zea mays* and *Capsicum annuum* intercropping, and clean tillage for younger orchards, and (ii) *Lolium perenne*, natural grass, and clean tillage for older orchards. Each treatment was assessed for its impact on fruit yield and financial benefits. In younger orchards, intercropping with *Z. mays* and *C. annuum* did not significantly elevate fruit yield compared to clean tillage in the 4-year-old orchard; however, *C. annuum* intercropping significantly improved fruit yield in the 5-year-old orchard. Concurrently, intercropping significantly augmented the total financial benefit by 9234.35–10,486.25 CNY ha^{−1} (*Z. mays*) and 14,304.90–16,629.18 CNY ha^{−1} (*C. annuum*) compared to clean tillage. In older orchards, *L. perenne* intercropping significantly elevated fruit yield by 598.84–803.64 kg·ha^{−1}, while natural grass reduced it by 394.61–986.24 kg·ha^{−1}, compared to clean tillage. Additionally, *L. perenne* intercropping significantly boosted the total financial benefit by 8873.92–9956.56 CNY ha^{−1}, whereas natural grass negatively impacted financial benefits by 78.42–2444.94 CNY ha^{−1} compared to clean tillage. Collectively, our results illustrate that judicious selection of intercrops, based on orchard age and conditions, can significantly enhance both fruit yield and financial advantages in *R. roxburghii* orchards. This study furnishes vital insights for orchard management and accentuates the prospective merits of intercropping in fruit production systems.

Keywords: intercropping; clean tillage; *Rosa roxburghii*; fruit yield; financial benefit

1. Introduction

Fruits are universally recognized for their vital contributions to human health, offering a rich supply of vitamins, organic acids, antioxidants, minerals, fibers, polyphenols, and other bioactive constituents [1–3]. With the continuous improvement in living standards, there has been a consistent rise in global fruit consumption [4,5]. Fruit orchards, occupying about 10% of the agricultural production land worldwide, are crucial in catering to this escalating demand [6]. Notably, China has established itself as the foremost producer and consumer of fruits on a global scale [7,8]. As reported by the FAO [9], between 2012

and 2021, China experienced an expansion in fruit cultivation area from 1.45×10^7 ha to 1.54×10^7 ha, and a surge in fruit production from 2.17×10^8 tons to 2.56×10^8 tons.

To enhance fruit yield, orchard cultivators employ a variety of agronomic practices. Among these, living mulch control, executed either mechanically or manually, is utilized to manage soil in fruit orchards. This strategy is adopted as living mulch can compete with fruit trees for essential resources such as water, nutrients, and light, which in turn may affect fruit production [10,11]. However, conventional clean tillage practices aimed at preserving soil fertility might inadvertently cause soil erosion and nutrient depletion due to frequent soil disturbance [10,12,13], thereby adversely impacting fruit yield [14,15].

Orchard intercropping, entailing the cultivation of additional crops in the alleys, has emerged as a multidisciplinary approach yielding multiple benefits for fruit tree cultivation. Prior research underscores the positive impact of intercropping on fruit quality, tree vigor, soil nutrient content, soil microbial activity, and microclimate conditions such as soil temperature and humidity [16–22]. By altering the conventional clean tillage model, orchard intercropping forms a soil–crop–atmosphere system, significantly affecting ground temperature and humidity [15,23–25]. Moreover, it optimizes temperature, humidity, water, and fertilizer utilization, thereby enhancing fruit tree growth [12,26–30]. Intercropping with aromatic plants such as *Rosmarinus officinalis*, *Ageratum houstonianum*, and *Ocimum basilicum* not only has shown no negative effects on natural enemies but also reduced primary insect population densities [31–33]. Hence, by increasing insect pollination, orchard intercropping with aromatic plants can potentially boost fruit yield. This practice has gained traction for its diversified production and efficient space utilization, allowing multiple crops or plants to coexist within the same agricultural area, complementing each other's growth and resource utilization [34–38].

The facilitation of changes in fruit production through orchard intercropping is primarily mediated by five categories of factors: orchard attributes, climatic conditions, edaphic variables, and managerial factors. Global meta-analysis by Fang et al. [39] revealed that compared to clean tillage, intercropping with legume species significantly bolstered fruit yield, while intercropping with non-legume species led to a significant reduction. However, a contrasting national meta-analysis in China by Ren et al. [35] indicated that both legume and non-legume species significantly enhanced fruit production, with legume species having a greater effect. The discrepancy in these findings could be attributed to the range of study areas and sample sizes. Furthermore, the yield-enhancing effect of intercropping varies with fruit tree types, for instance, citrus orchard intercropping yielded better results than apple orchard intercropping in China [35]. To attain higher fruit yield, it is suggested that a combination of 3–5 years of grass planting in regions with an average annual temperature of 15 °C or above, along with 5–10-year-old orchards, should be considered in China [35]. A meta-analysis by Morugán-Coronado et al. [40] investigating the influence of intercropping on fruit yield in a Mediterranean climate disclosed that fruit yield response to intercropping is closely associated with specific regional climatic conditions, with probable negative effects in warm and dry areas. Regarding the impact of grass mulch methods in orchards on fruit production, the yield-promoting effect of full mulching was found to be less than that of strip mulching [35], possibly because, under full mulching, orchard grass competes with fruit trees for nutrients, water, and root growth space.

Rosa roxburghii Tratt, a widely distributed shrub species primarily found in southwest China, especially in Guizhou province [41,42], is one of the diverse fruit-bearing plants that stands out. The fruits of *R. roxburghii* are revered for their medicinal properties and are gaining prominence for their potential in disease prevention and treatment [43–46]. Additionally, the *R. roxburghii* fruit industry plays a significant role in poverty alleviation, ecological development, and rural revitalization efforts [47]. Acknowledging its importance, the local government has prioritized the development of the *R. roxburghii* industry, listing it as a key agricultural sector in Guizhou. Despite the average yield of *R. roxburghii* falling below the desired level, there is a pressing need to improve both yield and fruit quality [48]. While various agronomic measures such as gibberellin application and pruning have been

explored to enhance *R. roxburghii* yield [49–52], the potential of orchard intercropping in the context of *R. roxburghii* cultivation remains largely unexplored.

To quantify the substantial benefits of orchard intercropping for enhancing sustainable and financially viable practices in *R. roxburghii* orchards, this study investigated the effects of intercropping on fruit yield and financial benefits in both 4- and 7-year *R. roxburghii* orchards. By scrutinizing the outcomes of diverse intercrops, this inquiry aims to unveil the potential of intercropping to elevate *R. roxburghii* yield and financial viability. The exploration of this is crucial for tailoring agronomic practices that could significantly benefit *R. roxburghii* cultivators in Guizhou province and potentially offer insights for other fruit orchards with similar agroecological characteristics. This study represents the endeavors to investigate the impacts of orchard intercropping on both fruit yield and financial benefits in *R. roxburghii* orchards, specifically in the context of southwest China. Through a comparative analysis of diverse intercrops in 4-year-old and 7-year-old *R. roxburghii* orchards, our findings would shed light on effective intercropping strategies that align with local agricultural practices, thereby providing a novel and practical approach to enhancing the sustainability and financial viability of *R. roxburghii* cultivation in this region.

2. Materials and Methods

2.1. Experimental Site

The study was conducted in two different towns in Longli County, Guizhou Province, China. The first study area was located in Gujiao town, at 106°58' E and 26°29' N. The area had an altitude of 1135 m and annual average temperature of 14.8 °C. The coldest monthly average temperature was 4.6 °C, and the hottest monthly average temperature was 23.6 °C. The annual precipitation was about 1100 mm, mostly concentrated in summer. The annual sunshine hours were 1160 h and the frost-free period was 283 days. The soil type is yellow soil with a thickness of 50–80 cm.

The second study area was located in Xima town, at 107°29' E, 26°18' N. The area had an altitude of 1150 m and annual average temperature of 14.6 °C. The coldest monthly average temperature was 4.9 °C and the hottest monthly average temperature was 24.2 °C. The annual precipitation was 1100 mm, mostly concentrated in summer. The annual sunshine hours were 1160 h and the frost-free period was more than 280 d. The soil type is yellow soil with a thickness of 50–80 cm.

2.2. Field Trial Design

The field trial was conducted at two different sites, Xima town and Gujiao town, to investigate the effects of intercropping on *R. roxburghii* orchards. Both sites featured 'Guinong No.5' variety of *R. roxburghii* with a row spacing of 2 m × 3 m, planted in the north–south direction. Fertilization was applied twice during the experiment using a compound fertilizer (N:P:K = 15:15:15) in early April and mid-July. All plots relied on rainfall, and herbicides were not used.

At Xima town, three planting patterns were designed: (1) intercropping with *Zea mays* ('Guiyu 1' variety) at a plant spacing of 0.30 m and a row spacing of 0.40 m, planted in early April; (2) intercropping with *Capsicum annuum* ('Guila 21' variety) at a plant spacing of 0.30 m and a row spacing of 0.40 m, planted in early April; (3) clean tillage (the control) with weeding conducted in March, July, and October. Randomized block design was followed for the research. Each planting pattern had three plots, each with an area of 225 m². Pruning was carried out in June and September. In the second year, the same experiment was continued, and the management mode of 5-year-old *R. roxburghii* and intercrops was the same as that in the first year.

At Gujiao town, a 7-year-old *R. roxburghii* orchard was selected for the study. The experiment involved three treatments: (1) planting of *Lolium perenne* L. ('Diamond T' variety) in the entire *R. roxburghii* orchard with a seeding rate of 22.5 kg ha^{−1}; (2) natural grass (comprising mainly *Setaria viridis*, *Digitaria sanguinalis*, *Imperata cylindrica*, *Eleusine indica*, *Oxalis corniculata*, etc.); (3) clean tillage (the control) with weeding conducted in

March, July, and October. Randomized block design was followed for the research. Each treatment had three plots, each with an area of 600 m². Pruning was carried out in June and September. In the second year, the same experiment was continued, and the management mode of 8-year-old *R. roxburghii* and intercrops was the same as that in the first year.

The difference between the two sites lies in the intercropping patterns (Figure 1): at Xima town, *Zea mays* and *Capsicum annuum* were intercropped with *R. roxburghii*, while at Gujiao town, intercropping involved natural grass and *L. perenne*.

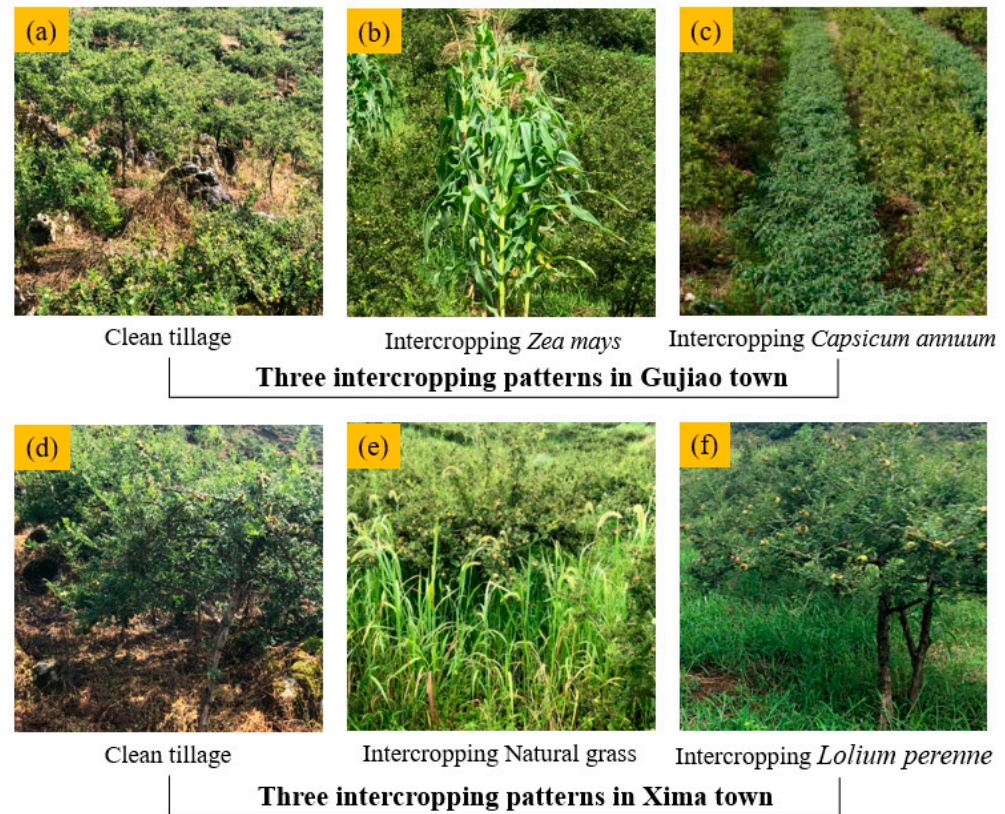


Figure 1. Pictures of two study sites. (a) Clean tillage, (b) Intercropping *Zea mays*, (c) Intercropping *Capsicum annuum* in Gujiao town; (d) Clean tillage, (e) Intercropping natural grass, (f) Intercropping *Lolium perenne* in Xima town.

2.3. Sampling and Yield Measurement

In order to obtain accurate and reliable data concerning the yield of *R. roxburghii* and intercropped species, meticulous sampling and measurement procedures were undertaken as outlined below:

***R. roxburghii* Yield Determination:** In September, at the mature stage of *R. roxburghii*, ten trees were randomly selected from each experimental plot for yield determination. The fruits from each selected tree were harvested, and their total weight was recorded. The yield per hectare was then calculated by extrapolating the average yield obtained from the ten sampled trees to the entire plot area, considering the planting density.

***L. perenne* and Natural Grass Management:** The mowing of *L. perenne* and natural grass was carried out four times a year, specifically in April, June, July, and September to maintain optimum growth conditions. During each mowing event, a 2 m² area was designated within each plot, and the fresh weight of the harvested grass was recorded between 3 and 5 pm during sunny weather to ensure consistent moisture content.

***Z. mays* Harvesting and Yield Calculation:** In October, a 2 m² area was selected within each plot for *Z. mays* grain sampling. The harvested grains were weighed to obtain the fresh weight, following which a 500 g subsample of grains was collected and placed in nylon mesh bags. The subsample was then taken to the laboratory, where it was dried to a

constant weight at 105 °C. The water content was subsequently measured to calculate the yield per hectare of *Z. mays* grain on a dry weight basis.

C. annuum Harvesting: In July, a 2 m² area was selected from each plot for sampling *C. annuum*. The harvested *C. annuum* was weighed to obtain the fresh weight. Unlike *Z. mays*, *C. annuum* was not subjected to drying as it is sold fresh, and thus, its fresh weight was used for yield and financial benefit calculations.

2.4. Financial Benefit Analysis

The basic parameters of the financial benefit analysis were obtained using an actual cost expenditure and market [53] (Tables 1–3). The investment unit price of *R. roxburghii* and intercrop cultivation is calculated by the actual expenditure. The fruit financial benefit of *R. roxburghii* is the sales income of *R. roxburghii* fruit minus the cultivation cost. The financial benefit of intercrops is the sales revenue of the edible part of the intercrops minus the cultivation cost. Total financial benefits of the intercropping system are equal to the financial benefit of *R. roxburghii* plus the financial benefit of intercrops. Because green management was performed in our *R. roxburghii* orchard and no pesticides were used during the experiment, there was no pesticide cost input. Table 2 shows the investment unit price parameters of the three intercropping methods. Because the investment cost of the two years of intercropping is the same, the investment discounting is not described in the text.

Table 1. Investment unit price of *R. roxburghii* cultivation.

Experimental Sites	Orchard Age (Year)	Pruning (CNY ha ^{−1})	Fertilization (CNY ha ^{−1})	Harvesting (CNY kg ^{−1})
Gujiao town	4–5	1200	2250	1
Xima town	7–8	2250	3000	1

Table 2. Investment unit price (CNY ha^{−1}) of intercrops.

Experimental Sites	Orchard Age (Year)	Treatments	Seed	Cultivation	Soil Scarification	Fertilization	Harvesting
Gujiao town	4–5	CT	0	0	4500	0	0
		ZM	900	1500	1500	2250	3000
		CA	1200	2250	3000	3000	4500
Xima town	7–8	CT	0	0	4500	0	0
		LP	1500	1200	1500	1500	4500
		NG	0	0	1500	0	0

Note: CT, clean tillage; ZM, *Zea mays*; CA, *Capsicum annuum*; LP, *Lolium perenne*; NG, natural grass.

Table 3. Sales unit price of *R. roxburghii* and intercrops (CNY kg^{−1}).

Crops	<i>R. roxburghii</i>	<i>Z. mays</i>	<i>C. annuum</i>	<i>L. perenne</i>
Unit price	5	3	4	0.5

2.5. Statistical Analyses

Microsoft Excel 2016 software was adopted to organize the experimental data. SPSS software (version 26) was used to test the normality of the data, and normally distributed data were subjected to variance analysis and multiple comparisons. Two-way ANOVA was followed for the research. The significance test for the mean of fruit yield and financial benefit was conducted using the least significant difference (LSD) test method. Data were visualized using OriginPro 2023 software.

3. Results

3.1. Effect of Intercropping on *R. roxburghii* Yield

The effect of intercropping on the fruit yield of *R. roxburghii* was related to the intercropping pattern and years (Figure 2). In the 4-year-old *R. roxburghii* orchard in Gujiao, compared with clean tillage, *Z. mays* and *C. annuum* did not significantly increase the fruit yield of *R. roxburghii* in the first year, but *C. annuum* increased the fruit yield of *R. roxburghii* in the second year ($p < 0.01$) (Figure 2a). In the 7-year-old *R. roxburghii* orchard in Xima, compared with clean tillage, natural grass and intercropping *L. perenne* in the first year did not significantly affect the fruit yield of *R. roxburghii*, but natural grass in the second year reduced the fruit yield of *R. roxburghii* ($p < 0.01$). *L. perenne* increased the fruit yield of *R. roxburghii* in the second year ($p < 0.05$) (Figure 2b). In addition, compared with natural grass, intercropping *L. perenne* increased the fruit yield of *R. roxburghii* ($p < 0.001$) in the second year of intercropping at the orchard in Xima. In the Gujiao orchard, continuous intercropping of *Z. mays* increased the yield of *R. roxburghii* ($p < 0.05$), while continuous intercropping of *C. annuum* increased the yield of *R. roxburghii* ($p < 0.01$) (Figure 2c). In the Xima orchard, continuous intercropping of *L. perenne* had a positive effect on the yield of *R. roxburghii* ($p < 0.01$) (Figure 2d).

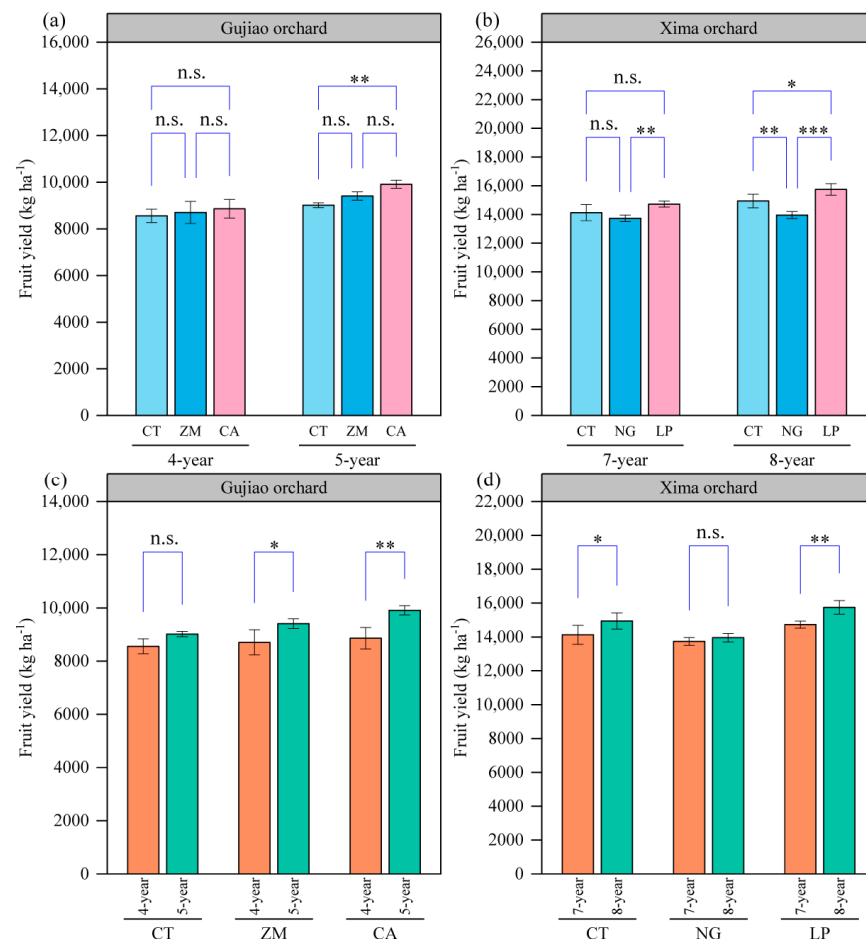


Figure 2. Fruit yield of *R. roxburghii* orchard under different intercropping modes and duration. Fruit yield of *R. roxburghii* between three intercropping modes (a) under 4 and 5-year-old in Gujiao orchard, and (b) under 7 and 8-year-old in Xima orchard, and fruit yield of *R. roxburghii* (c) between 4 and 5-year-old under three intercropping modes in Gujiao orchard, and (d) between 7 and 8-year-old under three intercropping modes in Xima orchard. n.s., *, **, and *** denote no significant difference, $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. CT, clean tillage; ZM, *Z. mays*; CA, *C. annuum*; NG, natural grass; LP, *L. perenne*.

3.2. Intercropping Effects on the Financial Benefits

3.2.1. Intercropping Effects on the Fruit Financial Benefits

The effect of intercropping on the fruit financial benefits of *R. roxburghii* was also related to the intercropping category and intercropping years (Figure 3). Specifically, in the 4-year-old orchard at the foot of the valley, compared with clean tillage, intercropping *Z. mays* and *C. annuum* in the first year did not significantly improve the fruit financial benefits of *R. roxburghii*; however, intercropping *C. annuum* in the second year had a very significant promotion effect on the fruit financial benefits of *R. roxburghii*, although natural grass in the second year reduced the fruit financial benefits of *R. roxburghii* ($p < 0.01$). *L. perenne* intercropping significantly increased the fruit financial benefits of *R. roxburghii* in the second year (Figure 3b). In the Gujiao town orchard, compared with the first year of intercropping, continuous intercropping *Z. mays* had a significant effect on the fruit financial benefits of *R. roxburghii*, and continuous intercropping *C. annuum* significantly increased the fruit financial effects of *R. roxburghii* (Figure 3c). In the orchard at Xima town, compared with the first year of intercropping, continuous natural grass did not increase the fruit financial benefits of *R. roxburghii* ($p > 0.05$), but continuous intercropping with *L. perenne* significantly increased the fruit financial benefits of *R. roxburghii* (Figure 3d).

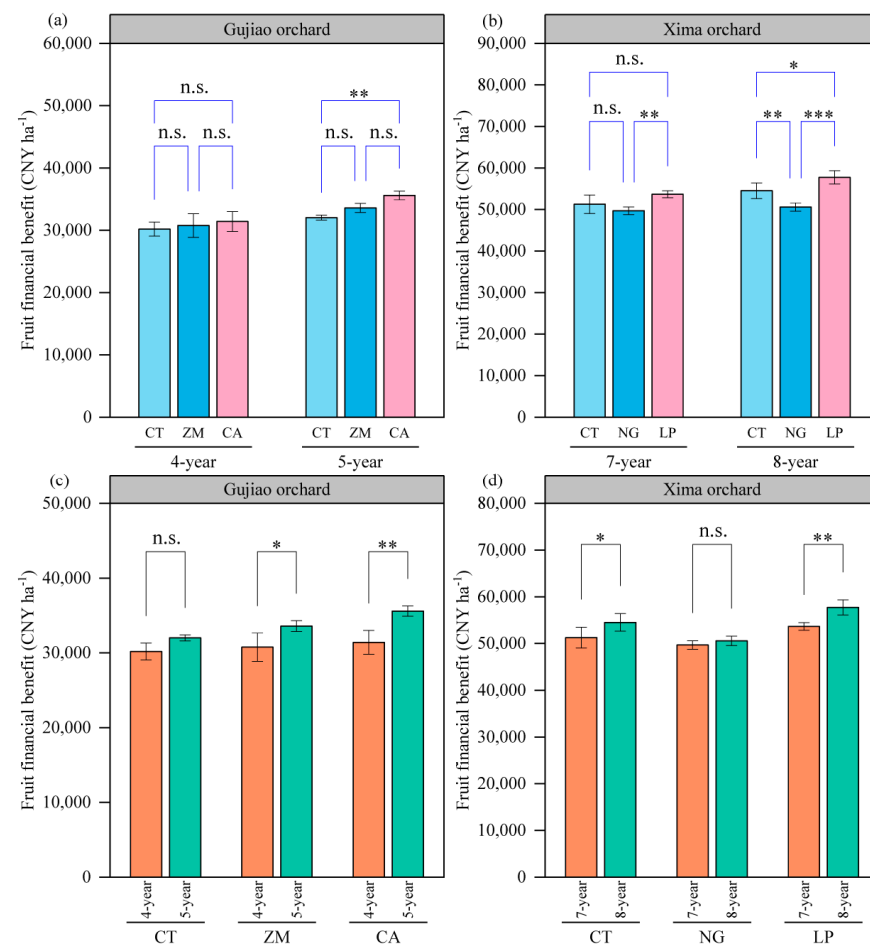


Figure 3. Fruit financial benefits of *R. roxburghii* under different intercropping modes and duration. Fruit financial benefits of *R. roxburghii* between three intercropping modes (a) under 4 and 5-year-old in Gujiao orchard, and (b) under 7 and 8-year-old in Xima orchard, and fruit financial benefits of *R. roxburghii* (c) between 4 and 5-year-old under three intercropping modes in Gujiao orchard, and (d) between 7 and 8-year-old under three intercropping modes in Xima orchard. n.s., *, **, and *** denote no significant difference, $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. CT, clean tillage; ZM, *Z. mays*; CA, *C. annuum*; NG, natural grass; LP, *L. perenne*.

3.2.2. Intercropping Effects on the Intercrops' Financial Benefits

The financial benefits of intercropping crops are mainly related to intercropping patterns (Figure 4). In the 4-year-old orchard at Gujiao town, the financial benefits of intercropping *Z. mays* were 4159.37–4414.49 CNY ha⁻¹, and the financial benefits of *C. annuum* were 8552.76–8592.78 CNY ha⁻¹ (Figure 4a). Because the yield of intercropping *C. annuum* (3882.00–3891.90 kg·ha⁻¹) is higher than that of *Z. mays* (2911.50–2995.50 kg·ha⁻¹), and the price of *C. annuum* is higher than that of *Z. mays*, the financial benefit of intercropping *C. annuum* is significantly higher than that of *Z. mays* ($p < 0.01$) (Figure 4a). In the 7-year-old orchard at Xima town, both clean tillage and natural grass have only inputs and no output, resulting in negative values of these two models, while the output of intercropping *L. perenne* is greater than the input, so the financial benefit of intercropping *L. perenne* is positive (Figure 4b). The financial benefits of intercrops were not significant ($p < 0.05$) due to the small changes in inter-annual crop yield and price (Figure 4c,d).

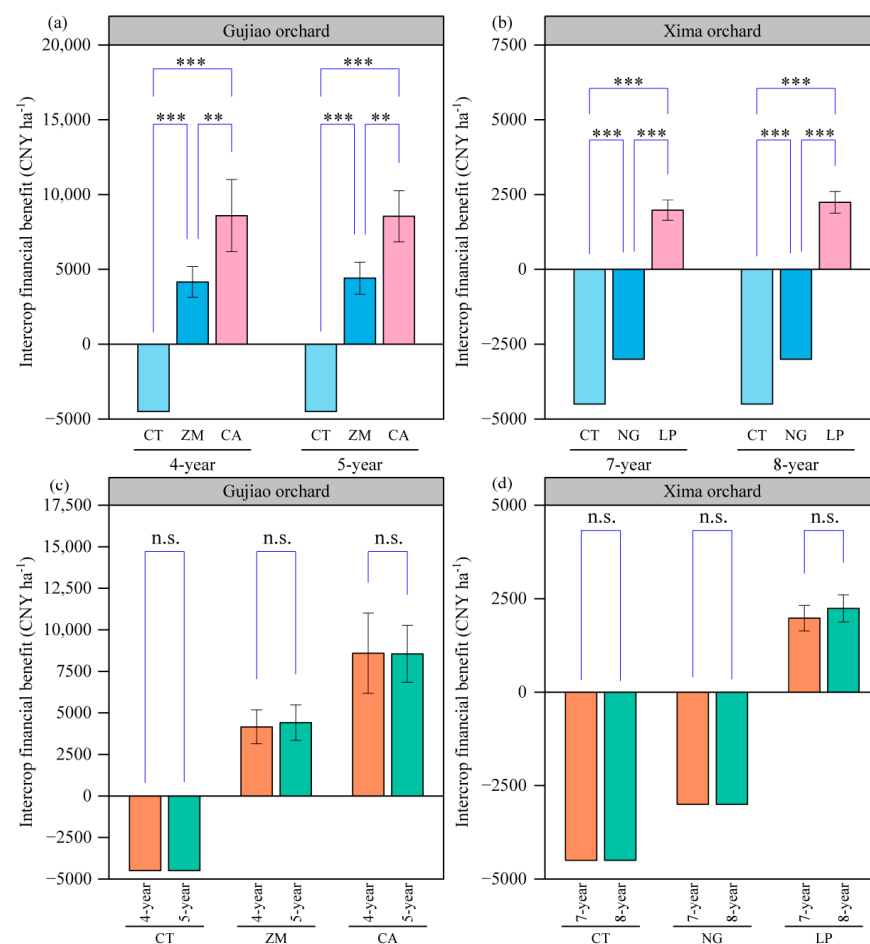


Figure 4. Intercrops' financial benefits of different intercropping modes and duration in *R. roxburghii* orchards. Intercrops' financial benefits between three intercropping modes (a) under 4 and 5-year-old *R. roxburghii* orchard in Gujiao town, and (b) under 7 and 8-year-old *R. roxburghii* orchard in Xima town, and intercrops' financial benefits (c) between 4 and 5-year-old *R. roxburghii* orchard under three intercropping modes in Gujiao town, and (d) between 7 and 8-year-old *R. roxburghii* orchard under three intercropping modes in Xima town. n.s., **, and *** denote no significant difference, $p < 0.01$, and $p < 0.001$, respectively. CT, clean tillage; ZM, *Z. mays*; CA, *C. annuum*; NG, natural grass; LP, *L. perenne*.

3.2.3. Intercropping Effects on the Total Financial Benefits

The total financial benefit of the intercropping system was closely related to the intercropping mode and the intercropping duration (Figure 5). In the 4-year-old and 5-year-

old orchard at Gujiao town, compared with clean tillage, the total financial benefits of the two intercropping modes of *Z. mays* and *C. annuum* were significantly increased by 9234.35–10,486.25 CNY ha⁻¹ and 14,304.90–16,629.18 CNY ha⁻¹, respectively (Figure 5a). In the first year of intercropping, the total financial benefit of the *R. roxburghii*–*C. annuum* intercropping mode was significantly higher than that of the *R. roxburghii*–*Z. mays* intercropping mode ($p < 0.05$), while in the second year of intercropping the total financial benefit of the *R. roxburghii*–*C. annuum* intercropping pattern was significantly higher than that of the *R. roxburghii*–*Z. mays* intercropping pattern ($p < 0.01$). In the 7-year-old and 8-year-old orchard at Xima town, compared with clean tillage, the natural grass intercropping pattern reduced the total financial benefit, while the *R. roxburghii*–*L. perenne* intercropping pattern significantly increased the total financial benefit, which was 8873.92–9956.56 CNY ha⁻¹ (Figure 5b). In terms of the total financial benefits of the same model in different years, only continuous intercropping of *C. annuum* had a significant effect on the total financial benefits in the Gujiao orchard ($p < 0.05$) (Figure 5c), whereas continuous intercropping of *L. perenne* significantly increased the total financial benefits in the Xima orchard (Figure 5d).

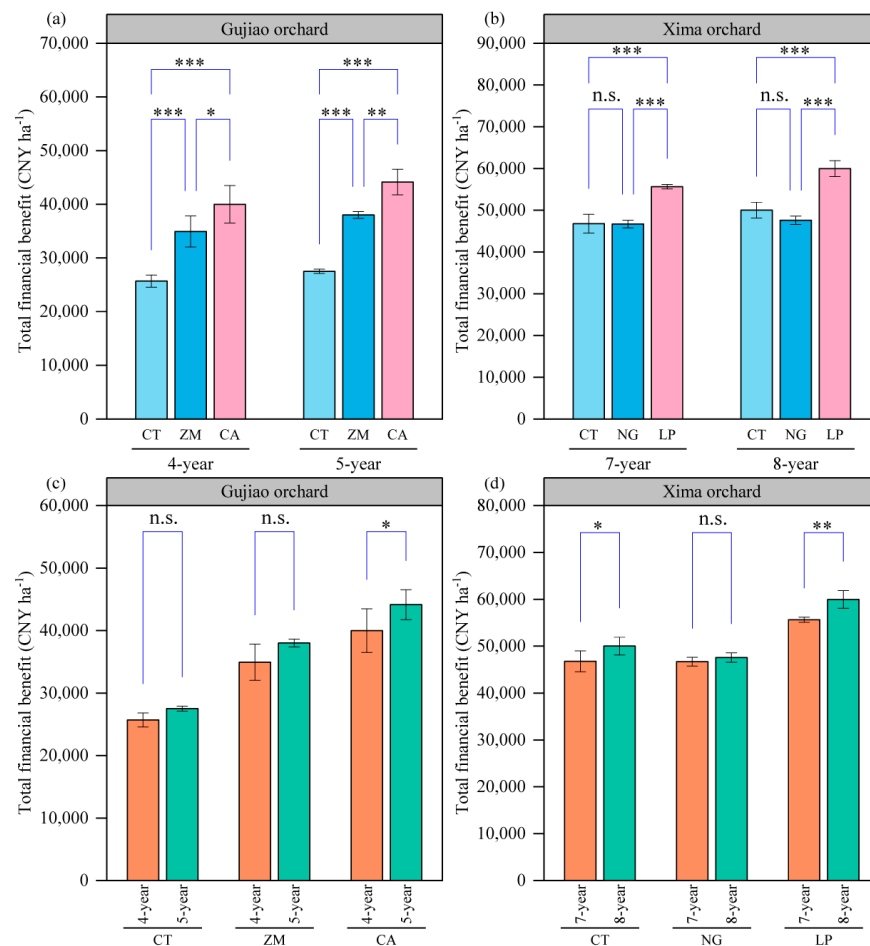


Figure 5. Total financial benefits of *R. roxburghii* orchards under different intercropping modes and duration. Total financial benefits of *R. roxburghii* between three intercropping modes (a) under 4 and 5-year-old in Gujiao orchard, and (b) under 7 and 8-year-old in Xima orchard, and total financial benefits of *R. roxburghii* (c) between 4 and 5-year-old under three intercropping modes in Gujiao orchard, and (d) between 7 and 8-year-old under three intercropping modes in Xima orchard. n.s., *, **, and *** denote no significant difference, $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. CT, clean tillage; ZM, *Z. mays*; CA, *C. annuum*; NG, natural grass; LP, *L. perenne*.

4. Discussion

The application of intercropping practices in orchards has garnered recognition for its capacity to optimize soil temperature and humidity, fostering an environment conducive to the robust growth of fruit trees [12,26,54]. Intercropping, when appropriately managed, can leverage the natural grass cover to enhance soil moisture retention by mitigating surface temperatures [10,55]. However, it is important to acknowledge that the interaction between natural grass growth and fruit yield is not universally positive. In scenarios where natural grass in the orchard exerts weak competition, it can potentially enhance soil moisture retention and benefit *R. roxburghii* growth. Yet, instances are prevalent where the presence of natural grass leads to reduced *R. roxburghii* yield due to aggressive weed competition for water and nutrients. In a contrasting approach, intercropping *R. roxburghii* with strategically chosen crops such as *C. annuum*, *Z. mays*, and *L. perenne*, positioned at intervals from *R. roxburghii* plants, effectively mitigated competitive pressures. Such intercropping not only curbed weed encroachment but also supplemented nutrients through practices such as soil aeration and weed management. The strategic intercropping involving *Z. mays*, *C. annuum*, and *L. perenne* proved particularly beneficial, fostering an environment conducive to *R. roxburghii* growth and ultimately yielding a notable increase in fruit yield. This finding is corroborated by Zhu et al. [56], whose research demonstrated that intercropping with Gramineae plants led to heightened Wolfberry productivity through the modification of soil characteristics and enzyme activities.

While our study did not uncover statistically significant differences in yield between intercropping and clean tillage treatments, it is pertinent to recognize that the relatively short intercropping duration in our investigation might not have allowed the intercropping system ample time to fully manifest its yield-enhancing potential. This observation aligns with findings from parallel studies [57] and underscores the dynamic nature of intercropping effects, which can evolve over extended timeframes. To further unravel the nuanced impact of intercropping on augmenting *R. roxburghii* yield, future research endeavors could contemplate prolonged intercropping periods. Moreover, investigating the broader influence of intercropping on dimensions such as fruit quality, tree vitality, and soil nutrient dynamics could yield comprehensive insights into the multifaceted benefits of intercropping strategies [58].

The financial benefit of intercropping strategies in *R. roxburghii* orchards emerges as a notable outcome of our study, particularly when compared to conventional clean tillage practices. In this context, intercropping *R. roxburghii* with crops such as *Z. mays*, *C. annuum*, and *L. perenne* yields promising financial benefits, while the presence of natural grass demonstrated a propensity to diminish overall profits. This observation underscores the pivotal role of judicious intercropping practices and effective weed management in maximizing the financial returns of *R. roxburghii* cultivation.

Within the realm of intercropping systems, *C. annuum* emerges as a standout, boasting the highest level of profitability. *Z. mays* and *L. perenne* follow, each presenting positive financial returns. In stark contrast, the clean tillage and natural grass treatments yield negative profits, essentially incurring input costs without commensurate output. Importantly, the amplified profitability stemming from intercropping the 4-year-old *R. roxburghii* orchard with *C. annuum* and *Z. mays* compared to the intercropping of the 7-year-old *R. roxburghii* orchard with *L. perenne* can be attributed to two key factors. Primarily, the larger intercropping area in the 4-year-old orchard enhances the scale of financial benefits. Furthermore, the higher unit prices commanded by *C. annuum* and *Z. mays* in comparison to *L. perenne* contribute significantly to the observed disparity. These observations elucidate the intricate interplay between orchard age, intercropping area, and crop unit prices.

In light of these insights, the selection of intercropping crops should be underpinned by a comprehensive understanding of local market dynamics and crop unit valuations. This strategic approach will enable cultivators to align their intercropping choices with prevailing market demands and capitalize on the most financially advantageous options. Finally,

the efficient intercropping patterns we screened have the opportunity to be sustainably and widely promoted [59].

Our research significantly contributes to the existing knowledge regarding orchard intercropping and its positive repercussions on both fruit yield and financial benefits [19,60–62]. Moreover, our observations regarding the advantageous impacts of *R. roxburghii* orchard intercropping on soil nutrient enrichment, microbial activity, and enzyme dynamics align with findings from previous studies [63,64]. However, we acknowledge the nuanced nature of intercropping effects on profitability, which could be influenced by diverse variables such as climatic conditions, soil attributes, management protocols, intercrop species, and intercropping duration. Further comprehensive research is imperative to thoroughly explore these factors, facilitating the broad adoption of *R. roxburghii* intercropping methodologies and promoting the sustainable growth of fruit orchard agriculture.

It is essential to recognize the limitations of our study. The relatively short duration of intercropping in our investigation might have restrained the full manifestation of its potential yield-promoting effects. This finding aligns with similar observations reported in related studies [57]. For a more robust evaluation of intercropping's impact, future studies should consider prolonged intercropping periods and delve into the intricate agronomic and agroecological mechanisms underlying the enhanced productivity observed in older *R. roxburghii* orchards (7 years old compared to 4 years old).

The residents near our experimental site like to eat *C. annuum* and *Z. mays*, so the financial benefits are better. At the same time, these two crops have strong adaptability in the local area, so they are selected as intercrops. In addition, the local aquaculture industry is relatively developed, and the demand for forage is large. Intercropping forage grass in *R. roxburghii* orchards can reduce nutrient loss caused by soil erosion and help to maintain soil fertility in orchards, thus promoting the growth of *R. roxburghii* trees and laying a foundation for high yield and high financial benefits. This shows that the selection of intercrops should take into account the needs of local residents so that the products produced can be sold well. Such intercropping modes can continue to develop.

Guesmi-Mzoughi et al. [65] reported that some intercrops, such as potato, tomato, and cucumber, generated an environment more advantageous to plant-parasitic nematodes infecting olive trees in Tunisia. Therefore, in order to test whether the intercrops host dangerous nematodes, the structure and diversity of plant-parasitic nematodes in *R. roxburghii* intercropping should be investigated. Intercropping with aromatic plants improved soil health by increasing soil organic matter in pear orchards [66], and hindered the occurrence of insects, such as *Proagopertha lucidela*, *Serica orientalis*, and *Maladera verticalis* [67]. A large number of beetle species love to feed on the twigs of *R. roxburghii* in summer, especially during drought periods, which led to reduction in *R. roxburghii* yield to a greater extent. Hence, it is necessary to study the biocontrol effect of intercropping aromatic plants on beetles in *R. roxburghii* orchards in the future. It is difficult to achieve high fruit yield by relying solely on intercropping crops to provide nutrients for *R. roxburghii* trees. It has been found that orchard intercropping grass resulted in the reduction in soil total phosphorus and available potassium [68], which suggests that orchard intercropping systems should also be given reasonable fertilization, especially of available nitrogen, phosphorus, and potassium compound fertilizer. Therefore, it is necessary to carry out fertilization experiments in combination with the age of *R. roxburghii* trees and soil background fertility to find a reasonable amount of fertilizer under intercropping. According to the growth of natural grass in orchards, weeding should be carried out in time. Timely cutting of the aboveground parts of the natural grass is necessary to use it as organic fertilizer for *R. roxburghii* orchards. Tougeron et al. [69] revealed that flower strips in an apple orchard provided a favorable condition to two parasitoid species, *Aphidius matricariae* and *Ephedrus cerasicola*, which effectively enhanced the control of rosy apple aphids. Future studies are needed to test which intercrops in *R. roxburghii* orchard are conducive to the survival of natural enemies of insects. In our study, *R. roxburghii* in the intercropping system was in the fruiting period, and it is necessary for us to study the intercropping mode of *R. roxburghii* saplings. Since the

financial benefits of intercropping may change over time, in order to obtain higher financial benefits of intercropping systems, fruit growers should choose suitable intercropping crops in *R. roxburghii* orchards according to the future market demands for those crops.

5. Conclusions

Our investigation underscores the potential advantages of intercropping as a financially viable practice for *R. roxburghii* orchards. The inclusion of clean tillage and natural grass as control treatments provided a comparative baseline, revealing their inadequacy in enhancing *R. roxburghii* yield. On the other hand, intercropping with *C. annuum*, *Z. mays*, and *L. perenne* significantly improved both the yield and financial benefit of *R. roxburghii* cultivation when compared to clean tillage practices. This knowledge holds immense value for researchers and farmers, both in China and globally, who are engaged in orchard intercropping. The adoption of intercropping strategies can improve orchard conditions, elevate fruit yield, and ultimately, augment the financial benefits of *R. roxburghii* cultivation, which may contribute to the financial benefit of the *R. roxburghii* fruit industry.

While our study provides insightful contributions to this field, we recognize certain experimental limitations, such as fewer test repeats, the two-year experimental span, and the selection of intercropping crops based on regional availability. Future endeavors should set more repetitions to minimize the deviation in research results caused by soil heterogeneity in the field, and consider long-term studies to assess the persistent effects of intercropping on *R. roxburghii* yield and financial benefits across multiple cropping seasons. Moreover, exploring alternative intercropping combinations and crop rotations, alongside comprehensive cost–benefit analyses, may unveil insights into the most suitable intercropping strategies for diverse *R. roxburghii* orchards and regional scenarios. Further research could also delve into the ecological interactions between intercropped species to better understand and demonstrate the sustainability aspect of intercropping systems in *R. roxburghii* orchards.

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