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In Arid Regions, Forage Mulching between Fruit Trees Rows Enhances Fruit Tree Light and Lowers Soil Salinity

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Abstract: Agroforestry is considered a means to provide sustainable and productive agriculture. This work aims to study the effect of fruit-grass agroforestry patterns on the soil moisture, salinity, growth, and yield of fruit trees, as well as to provide a reference for the development of agroforestry complex systems in Northwest China. The study has been designed with two cropping patterns: monocropped apple and apple-ryegrass intercropping. The results showed that compared to monocropped apples, intercropped apples have increased soil moisture content by 33.38–39.02%, net photosynthetic rate by 35.33–42.26%, transpiration rate by 29.62–29.76%, and stomatal conductance by 15.65–16.55% in the 0–60 cm soil layer. Intercrop reduced the total soil salt content by 36.41–38.58%, and the intercellular CO_2 concentration decreased by 5.96–6.61%. In addition, intercropping improves fruit yield and quality by improving the orchard environment and increasing tree height, breast height, north-south crown spread, and east-west crown spread. Therefore, increased yield and quality can be achieved by changing the fruit tree and ryegrass planting method, which is beneficial to the sustainable development of agriculture in Northwest China.

Keywords: apple-ryegrass intercropping; photosynthetic characteristics; soil salinity; soil moisture content; fruit quality

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1. Introduction

Soil salinization is a major constraint to sustainable agricultural development in arid and semi-arid regions [1]. Xinjiang, which is located in the hinterland of Asia and Europe, where precipitation is scarce, and evaporation is high, making it a typical arid and semi-arid region, is a region in China where wind-sand disasters are serious, with the widest distribution of saline soil areas and the greatest degree of salinization. In particular, in the south of Xinjiang, the high level of sand and wind damage and saline soils greatly impair the growth and development of crops, resulting in low yields and economic returns.

This area is located at the edge of the desert and is often affected by wind-sand disasters and increased saline–alkali soils, which further exacerbates the quality of the land. As such, how to use reasonable measures to control and govern soil salinization is an issue that must be addressed. At present, the main measures used in Xinjiang to amend soil salinization are engineering, chemical, and biological measures [2]. Among them, engineering measures, although fast and effective, are costly and constrained by water shortages, making it difficult to promote them in arid and semi-arid areas. These measures can wash away water-soluble nutrients in the soil, resulting in the loss of soil nutrients [3]. Chemical measures are quick to work in the short term, but there are restrictions to their use on a large scale due to the limitations of the improvers and costs [4]. Biological measures refer to planting saline-tolerant plants in salinized areas to gradually reduce the harm of salinity to plants through the physiological function of plants and the influence of the root system on the physical and chemical properties of soil, which achieves the purpose of improving saline soil.

At present, most fruit trees are planted in saline soils in South Xinjiang, which seriously affects the yield and quality of these trees. The tree-based intercropping system is largely favored by the local population to achieve better yield and benefits. Intercropping of trees and crops has been traditionally practiced in China for centuries [5]. Scientists and growers understand that adding trees to an agricultural system offers various additional benefits, also known as ecosystem services, to the farmer and society [6]. Meanwhile, planting salt-tolerant forage grasses on saline soils can increase the ground cover, replace soil evaporation with plant transpiration and reduce soil evaporation, thus reducing the rate of soil salt accumulation and reducing the accumulation of salt in the surface layer, thus achieving desalination [7]. Therefore, the tree-based agroforestry system has been established on the salt-affected soils in the south of Xinjiang, and fruit tree/crop intercropping has become the dominant land-use type for ameliorating the saline conditions of soils in the area.

Different land use patterns determine the differences in the soil water content and salinity distribution. The factors affecting soil water content are variable at different spatial and temporal scales [8,9]. Planting alfalfa between tree rows allows the open space between the rows to be covered, allowing the system to effectively block soil moisture loss due to seasonal drought [10]. However, in arid and semi-arid regions, strong plant transpiration leads to large consumption of soil water, negatively affects the natural distribution characteristics of soil water, reduces the differences in soil water distribution, and changes the soil structure [11]. Forest-grass intercropping has a greater leaf area index and consumes soil water too quickly [12].

Intercropping is generally considered to have a greater increase in tree height and crown growth rate than clear-cutting. However, some studies [13] have shown that whole orchard grassing can significantly reduce tree growth, with newly planted trees being particularly sensitive. Intercropping not only provides favorable conditions for the growth of fruit trees but also improves fruit quality. Orchard grassing increased the soluble solids, hardness, and Vc content of apples, but the effect on yield per plant and fruit quality per fruit was not significantly different from that of clear-cut areas [14]. At the same time, a good orchard environment can also create conditions for high fruit quality and yield. Grass in orchards can reduce air temperature during the high-temperature period, moderate air temperature fluctuations, increase the relative humidity of the orchard air, maintain a high air humidity in the orchard, and form an air temperature and humidity environment that is conducive to the growth and development of fruit trees and various physiological activities [15].

Halophytes can absorb salt ions in the soil and improve saline soil [16]. At the same time, halophytes have desalination and restoration potential with respect to saline soils and can be used in phytoremediation [17]. Some research has shown that alfalfa can absorb salts from the soil, resulting in a significant decrease in the soluble salt content of the soil [18,19]. Planting alfalfa in woodland can play a role in reducing soil salinity and can effectively reduce soil salinity beneath the woodlands. Meanwhile, canopy shading has a promotional effect on the growth of pastures in the presence of some water stress [20].

South Xinjiang is located near the Taklamakan Desert, where sandy and dust weather is frequent. This can have a negative impact on the growing environment of native plants. The effects of dust on plant growth and development are manifold, especially on photosynthesis [21]. It was speculated that dust decreased the photosynthetic rate by shading the leaf surface. Meanwhile, the dust increased the transpiration rate by increasing the leaf temperature [22]. In addition, dust may cause physical injury to tree leaves and bark, reducing fruit setting and resulting in a general reduction in growth [23]. Dust can also cause important changes to leaf physiology, affecting tree productivity [24].

In conclusion, soil salinity, sand, and dust have certain harmful effects on plant growth. At present, there are few studies on the effects of intercropping on soil salinization and sand and dust [7,23]. In this study, we select South Xinjiang, where soil salinization and sand and dust are serious, as the study area and use apple and ryegrass as experimental materials. The purpose was to understand the following.

1. Which cropping pattern has a beneficial effect on managing soil salinization?
2. Which planting pattern can weaken sand and dust hazards and improve the photosynthetic capacity and fruit quality of fruit trees?

We hypothesize that (1) this type of intercropping system can have a beneficial effect on salinity management by changing the soil salt ion concentrations and (2) this type of intercropping system has a positive impact on weakening dust damage and improving fruit yield and quality.

2. Materials and Methods

2.1. Experimental Site

The field experiments were carried out in 2020 and 2021 at the Fruit Core Demonstration Base of the 44th Regiment of the 3rd Division of the Xinjiang Production and Construction in crops (79°18′ E, 39°84′ N). This area has a temperate, extremely arid desert climate with long sunshine hours and large temperature differences between day and night. The average annual temperature is 11.6 °C, and in the hottest month (July), the average temperature is 25–26.7 °C, the coldest month (January) has an average temperature of −6.6–−7.3 °C, the annual average frost-free period is 221–225 days, and the annual rainfall is 38.3 mm.

2.2. Experimental Design

The experimental design employed two treatments: sole-cropped apple (MA) and apple/ryegrass intercropping (IR). The experimental plot area is 24 × 20 m^2. Each treatment plot is 24 × 8 m^2 in size and has 72 apple trees. The apple tree + ryegrass intercropping system was established in 2019 in arable cropland fields. Apple trees were transplanted in 2019. Apple trees were three years old. The average height of apple trees was 1.90 m, the diameter at breast height was 2.11 cm, the north-south crown amplitude was 1.25 m, and the east-west crown amplitude was 1.42 m.

The planting layout of each test plot is shown in Figure 1. The ARI system plot, had a 100 cm wide bare area between apples and ryegrass. The spacing of tree rows is 4.0 m, and the spacing between trees in each row is 1.0 m. Apple trees were planted 2.5×10^3 plants/hm^{-2}. Ryegrass was seeded between the apple rows at a seeding density of 20 kg/hm^2, a row spacing of 0.25 m, and a sowing depth of 2.0 cm. The sole-cropped apple system used the same pattern as intercropping, bare land between trees and no other crops. The sole-cropping fields in each experimental site were used as the control plots that included the same cultivars, the same planting and cultivation modes, the same previous agricultural system, and the same agricultural management system in intercropping and sole-cropping systems. The samples were collected in mid-July (flowering and fruiting period), late August (fruit enlarging period), and late September (fruit maturing period).

2.3. Soil Sample Collection

2.3.1. Soil Sample Collection

According to the sampling plan described above, soil samples were collected from a randomly selected apple tree of good growth in the middle row of the monocrop and intercrop systems to study the distribution of soil moisture and salinity. Sampling was carried out by the auger sampling method, using the tree as the origin and sampling in a horizontal radial direction at 50 cm, 100 cm, 150 cm, and 200 cm from the tree at depths of 0–20 cm, 20–40 cm and 40–60 cm, replicated three times.

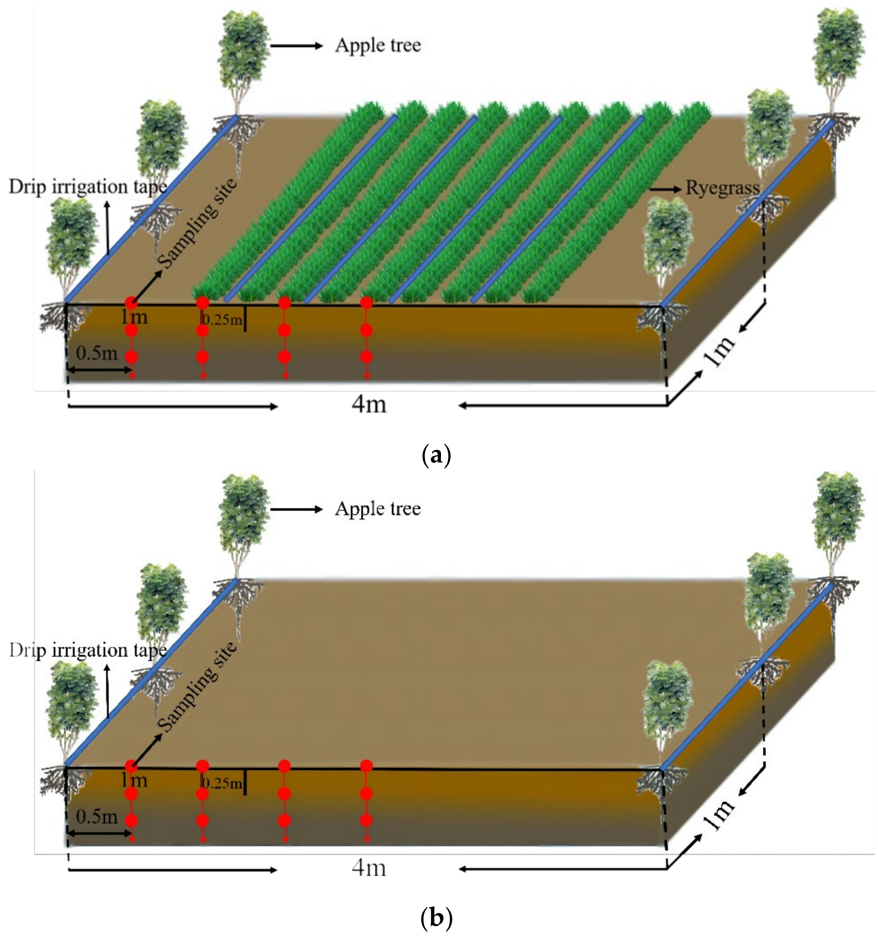

Figure 1. (**a**): diagram of apple and ryegrass planting in an apple/ryegrass intercropping system; (**b**): diagram of apple growing in an apple monoculture system.

2.3.2. Measurement of Soil Moisture Content and Soil Salinity

In accordance with the sampling time, the completed soil samples are placed partly in aluminum boxes for the determination of the soil water content and partly for the determination of the soil K^+ and total salt content. Soil moisture content is determined by the drying method, whereby the soil samples are dried in an oven in an aluminum box, and the soil moisture content is calculated by comparing the soil weight before and after drying. The other part of the soil sample is air dried and passed through a 2 mm sieve, mixed at a 5:1 ratio of water to soil, oscillated, and the supernatant extracted to determine the soil K^+ and total salt content. The soil K^+ content was determined using Plasma Emitted Atomic Spectrometer (ICAP6300), while the soil's total salt content was determined by conductivity.

2.4. Measurement of Microclimate on Farmland

According to the sampling period, air temperature, relative air humidity, and wind speed were measured in the apple monoculture and the apple-ryegrass intercropping systems. A day of continuous good weather was selected, and measurements were taken once in the morning and once in the afternoon using a Kestrel 4000 handheld weather station and repeated three times.

2.5. Measurement of Photosynthetic Characteristics

Depending on the above measurement times, photosynthetic parameters were selected from 10:00 to 12:00 on a sunny day. Within the apple monocropping and apple-ryegrass intercropping systems, three well-grown apple trees were randomly selected, and the photosynthetic parameters, including net photosynthetic rate (Pn), stomatal conductance (Gs), intercellular CO_2 concentration (Ci) and translocation rate (Tr) of the middle functional leaves of apple trees were measured using an LI-6400 photosynthetic instrument and replicated three times.

2.6. Measurement of Fruit Tree Growth Indicators, Yield and Fruit Quality

In October 2020 and 2021, we randomly selected three good growth apple trees and measured the standard tree height and crown width with a steel tape measure and the diameter at breast height with a vernier caliper, replicated three times. At the same time, the number of fruits from standard apple trees was counted, and 60 apples were collected randomly in each treatment plot and preserved in ice boxes. Individual fruit weights were determined using a 1/100 electronic balance, and individual plant yields were calculated. Soluble solids were determined using a WYT-4 handheld sugar meter; hardness was determined using a GY-1 fruit hardness tester; soluble sugar content was determined using the anthrone colorimetric method, and total acid content was determined using the NaOH neutralizing titration method.

2.7. Statistical Analysis

Analysis of variance was performed on the data using SPSS ver. 22.0. Among them, the least significant difference method was used for multiple comparison analysis, and the significance level was set as a = 0.05. Origin 2022 and Sufer15 were used for graphing.

3. Results

3.1. Effect of Planting Patterns on the Soil Moisture Content

The two-dimensional distribution characteristics of the soil water content (Figure 2) showed that the soil water content increased with increasing soil depth and decreased with increasing distance from the tree row in both monocropped and intercropped apple systems. A comparison of the soil water content between monocropped and intercropped apples revealed that intercropping ryegrass with apples significantly increased the soil water content at the flowering and fruiting periods (50, 40), (150, 20), (150, 60) and (200, 20) by 33.66%, 53.90%, 34.62%, and 45.66%, respectively (Figure 2a,d,g,j). During the fruit enlarging period, intercropping significantly increased the soil water content of (50, 20), (100, 20), (150, 20), (200, 20), and (200, 40) by 46.95%, 42.92%, 33.80%, 41.53%, and 35.03%, respectively (Figure 2b,e,h,k). At the fruit maturing period, intercropping significantly increased the soil water content in (50, 20), (50, 40), (100, 20), (100, 40), (150, 20), (150, 40), (200, 20), (200, 40), and (200, 60) by 46.38%, 45.73%, 64.86%, 52.95%, 92.55%, 53.72%, 62.16%, 53.29%, and 42.84%, respectively (Figure 2c,f,i,l). The variation in the soil water content was higher in the zero to 20 cm soil layer and lower in the 40–60 cm soil layer, showing that apples intercropped with ryegrass can effectively increase the soil water content.

3.2. Effect of Planting Patterns on Soil Salinity

The two−dimensional distribution characteristics of the soil Na^+ content are shown in Figure 3. In both monocropped and intercropped apple systems, the soil Na^+ content increased with increasing soil depth and did not vary significantly with increasing distance from the tree, and the variation in the soil Na^+ content between different fertility periods was not significant. A comparison of the soil Na^+ content between monocropping and intercropping showed that apple intercropping with ryegrass significantly reduced (50, 20), (50, 40), (100, 20), (100, 40), (150, 20), (150, 40), (200, 20), (200, 40) the soil Na^+ content by 52.33%, 41.96%, 50.09%, 33.89%, 52.13%, 34.98%, 51.31%, and 34.31%, respectively. Intercropping significantly reduced the Na^+ content in the zero to 40 cm soil layer. This is because the addition of mulch between fruit rows changed the soil structure, increased the soil water content, and contributed to the downward transport of soil Na^+ with water.

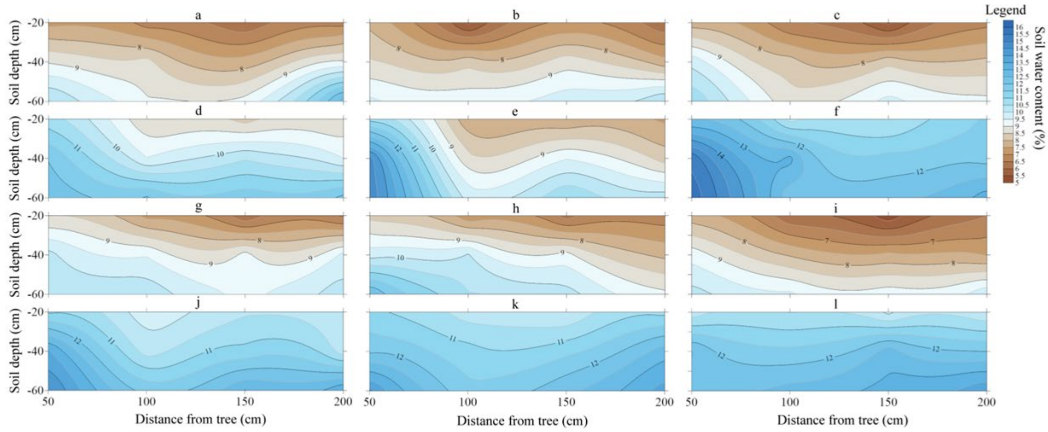

Figure 2. Two−dimensional soil moisture content distribution in different stages of monocropping apple and ryegrass apple intercropping system ((**a**,**d**,**g**,**j**): flowering and fruiting period; (**b**,**e**,**h**,**k**): fruit enlarging period; (**c**,**f**,**i**,**l**): fruit maturing period; monocropping apple (first and third rows) and ryegrass apple intercropping system (second and fourth rows); in the 2020 (top two rows) and 2021 (bottom two rows) seasons).

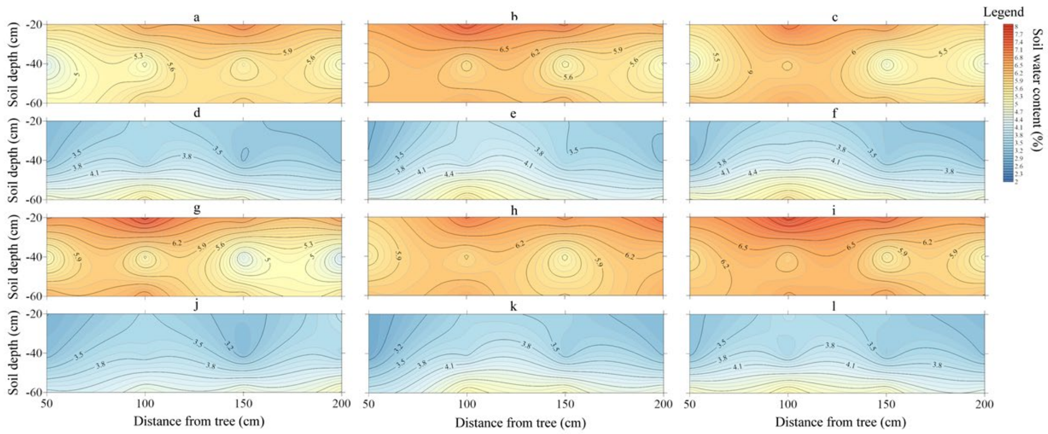

Figure 3. Two−dimensional soil Na^+ content distribution in different stages of monocropping apple and ryegrass apple intercropping system ((**a**,**d**,**g**,**j**): flowering and fruiting period; (**b**,**e**,**h**,**k**): fruit enlarging period; (**c**,**f**,**i**,**l**): fruit maturing period; monocropping apple (first and third rows) and ryegrass apple intercropping system (second and fourth rows); in the 2020 (top two rows) and 2021 (bottom two rows) seasons).

The two-dimensional distribution characteristics of the soil's total salt content are shown in Figure 4. In both monocropped and intercropped apple systems, the soil total salt content increased with increasing soil depth and did not change significantly with increasing distance from the tree. The comparison between the monocrop and intercrop revealed that intercropping significantly reduced (50, 20), (100, 20), (150, 20), and (200, 20) the soil total salt content by 54.29%, 51.79%, 54.95%, and 48.8%, respectively, during the flowering and fruiting period (Figure 4a,d,g,j). At the fruit enlarging period, intercropping reduced (50, 20), (50, 40), (100, 20), (150, 20), (200, 20), and (200, 40) the soil total salt content by 56.39%, 52.33%, 50.63%, 51.38%, 56.12%, and 44.27%, respectively (Figure 4b,e,h,k). During the fruit maturing period, intercropping significantly reduced (50, 20), (50, 40), (100, 20), (150, 20), and (200, 20) the soil total salt content by 49.1%, 41.12%, 50.14%, 53.22%, and 52.43%, respectively (Figure 4c,f,i,l). Intercropping significantly reduced the total salt content in the zero to 20 cm soil layer, and the reduction was greater at the fruit expansion stage. This is because, during the fruit expansion period, plants need more water, salts are transported downward with water, and the total salt content in the soil surface layer is significantly reduced. Therefore, intercropping can effectively improve the distribution of total soil salt in the 0–20 cm soil layer and reduce the soil salt content in the 0–40 cm soil layer, thus reducing the toxic effect on plants.

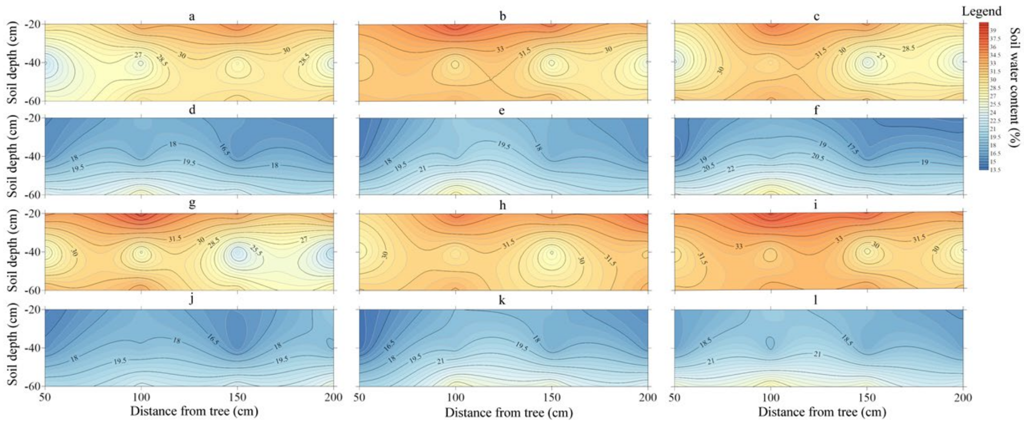

Figure 4. Two−dimensional soil total salt content distribution in different stages of monocropping apple and ryegrass apple intercropping system ((**a**,**d**,**g**,**j**): flowering and fruiting period; (**b**,**e**,**h**,**k**): fruit enlarging period; (**c**,**f**,**i**,**l**): fruit maturing period; monocropping apple (first and third rows) and ryegrass apple intercropping system (second and fourth rows); in the 2020 (top two rows) and 2021 (bottom two rows) seasons).

3.3. *Effect of Planting Pattern on the Orchard Microclimate*

Observations showed that temperature, humidity, and wind speed of intercropped ryegrass orchards differed significantly from those of monocropped orchards (Figure 5). The air temperature and wind speed in intercropped ryegrass orchards were lower than those in monocropped orchards at different fertility periods, with decreases of 5.93%, 6.26%, 6.03% (Figure 5A), 12.33%, 11.21%, and 11.91% (Figure 5C). The relative humidity of air in intercropped ryegrass orchards was greater than in monocropped orchards, increasing by 10.76%, 16.11%, and 14.37% (Figure 5B). It can be seen that the planting of ryegrass reduced the wind speed, weakened the translational velocity of the airflow, reduced the turbulent exchange effect, increased the soil moisture between apple rows, and increased the relative humidity of air in the orchard. Ryegrass also transpires during the growth process, absorbing some of the heat and lowering the orchard temperature. Therefore, intercropping can significantly increase the relative humidity of orchard air, significantly reduce the temperature and wind speed in the orchard, and improve the wind protection effectiveness of the orchard. Intercropping had no significant interannual effect on the orchard microclimate.

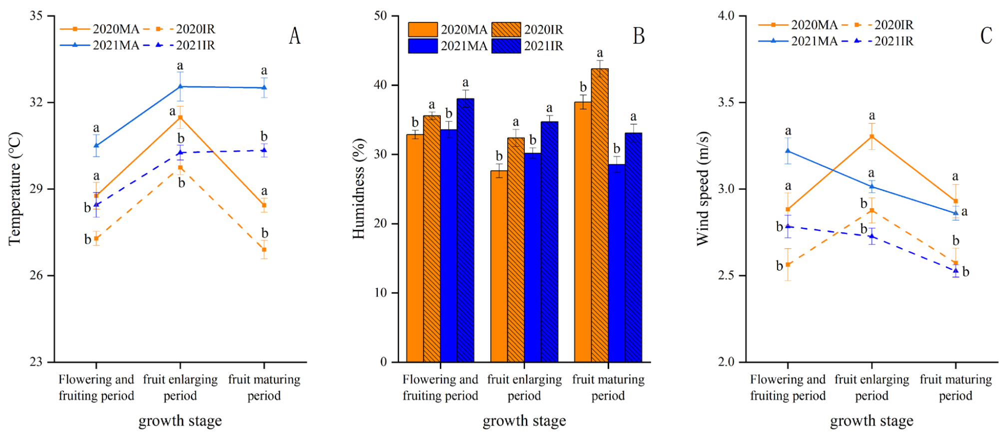

Figure 5. Schematic diagram of temperature, humidness, and wind speed changes in different stages of monocropping apple and ryegrass apple intercropping system. ((**A**): temperature; (**B**): humidness; (**C**): wind speed, Different lowercase letters in the graph indicates significant differences across treatments ($p < 0.05$).).

3.4. Effect of Planting Pattern on the Photosynthesis of Fruit Trees

Plant photosynthesis is a complex physiological and biochemical reaction influenced by several environmental factors, such as light intensity, temperature, and water. As shown in Figure 6, "the measuring parameters" Pn, Tr, Ci, and Gs of intercropped apples were significantly different from those of monocropped apples. As apple fertility progressed, the Pn, Tr, and Gs of intercropped apples were greater than those of monocropped apples, reaching the maximum at fruit maturity, which increased by 13.18%, 40.04%, and 58.7% (Figure 6A); 19.62%, 32.59%, and 36.86% (Figure 6B); 6.51%, 16.01%, and 25.78% (Figure 6D). The Ci of intercropped apples was less than that under monocropping and reached the minimum value at fruit ripening, which decreased by 3.43%, 6.17%, and 9.26% (Figure 6C). Intercropping increased Pn, Tr, and Gs and decreased Ci because intercropping reduced the orchard temperature, increased humidity, and reduced the "lunch break" phenomenon of apple leaves. In addition, due to the local dusty weather, the lack of forage mulching between the rows of monocropped apples, and the high amount of bare land blown by the wind, there was more sand and dust on the surface of the apple leaves, which blocked the stomata and reduced the transpiration rate of the apple leaves. Intercropping had no significant interannual effect on the photosynthesis of the apple leaves.

3.5. Effect of the Planting Pattern on Fruit Tree Yield and Fruit Quality

Different cropping patterns can change the growth traits of apple trees (Table 1). In 2020, the height, breast height, north-south crown amplitude, and east-west crown amplitude of intercropped apples increased by 0.09 m, 0.08 cm, 0.12 m, and 0.12 m, respectively, compared to monocropped apples, with increases of 3.37%, 2.69%, 7.89%, and 7.64%. In 2021, intercropping increased the height, breast height, north-south crown amplitude and east-west crown amplitude, by 0.07 m, 0.15 cm, 0.16 m, and 0.12 m, or 2.03%, 3.92%, 9.04%, and 6.98%, respectively. However, although intercropping increased the height, breast height, north-south crown amplitude, and east-west crown amplitude of apples, the magnitude of the increase did not vary significantly. At the same time, the inter-annual variation was not significant. Therefore, intercropping improves the growth of apple trees by increasing the soil water content and improving the microclimate of the orchard.

As shown in Table 2, intercropping affected the external quality of apples, and there were significant differences between monocropping and intercropping. The single fruit weight, fruit hardness, and single plant yield of intercropped apples were significantly greater than those of monocropped apples, which increased by 10.8%, 8.2%, and 11.02%, respectively. The soluble sugar and sugar-acid ratios of intercropped apples were significantly greater than those of monocropped apples, with increases of 5.07% and 10.9%; titratable acid was significantly lower than that of monocropped apples, with a decrease of 5.5%; soluble solids and Vc were not significantly different from those of monocropped apples. This showed that intercropping significantly increased the single fruit weight, fruit hardness, yield per plant, and soluble sugar and sugar-acid ratio and reduced the titratable acid content of the apples. Intercropping had no significant effect on apple quality from year to year.

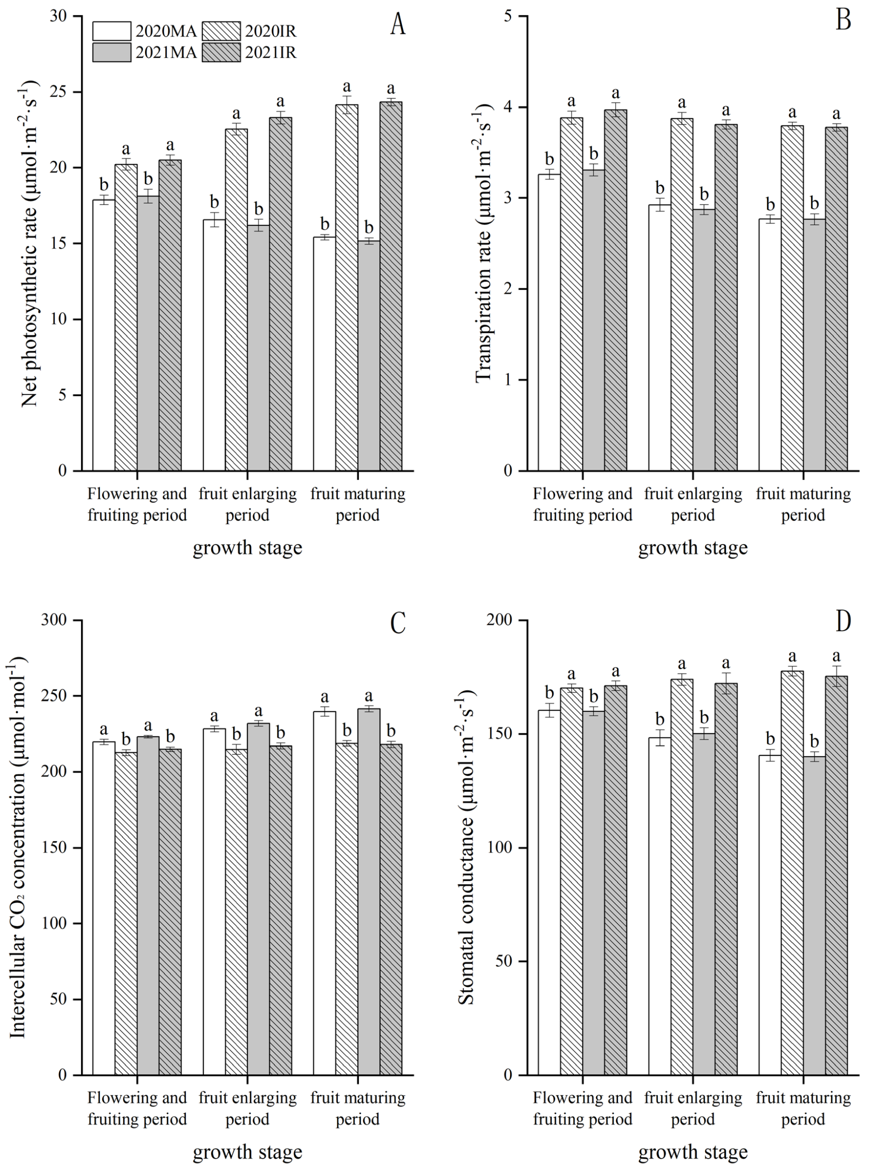

Figure 6. Schematic diagram of changes in net photosynthetic rate, transpiration rate, intercellular CO_2 concentration, and stomatal conductance in different stages of monocropping apple and ryegrass apple intercropping system. ((**A**): net photosynthetic rate; (**B**): transpiration rate; (**C**): intercellular CO_2 concentration; (**D**): stomatal conductance, Different lowercase letters in the graph indicates significant differences across treatments ($p < 0.05$)).

Table 1. The growth indicators of fruit trees in different planting patterns.

Year	Treatment	Tree Height (m)	Breast Height (cm)	The North-South Crown Amplitude (m)	The East-West Crown Amplitude (m)
2020	MA	2.67 ± 0.14 a	2.97 ± 0.16 a	1.52 ± 0.05 a	1.57 ± 0.02 a
	IR	2.76 ± 0.17 a	3.05 ± 0.08 a	1.64 ± 0.06 a	1.65 ± 0.05 a
2021	MA	3.44 ± 0.11 a	3.83 ± 0.12 a	1.77 ± 0.04 a	1.72 ± 0.05 a
	IR	3.51 ± 0.09 a	3.98 ± 0.19 a	1.93 ± 0.06 a	1.84 ± 0.06 a

MA- monocropped apples; IR- intercropped apples. The same letters in the same column indicated no significant difference at 0.05 level in Duncan's analysis.

Table 2. The appearance and internal quality of the fruit in different planting patterns.

Year	Treatment	Single Fruit Weight (g)	Fruit Firmness (kg/cm^2)	Soluble Solids (%)	Soluble Sugar (%)	Titratable Acid (%)	Sugar to Acid Ratio	Vc (mg/100g)	Single Average Yield (kg)
2020	MA	206.06 ± 10.76 b	9.89 ± 0.44 a	14.82 ± 0.32 a	10.14 ± 0.33 a	0.42 ± 0.05 a	24.59 ± 3.50 a	5.57 ± 0.13 a	1.03 ± 0.05 a
	IR	227.54 ± 7.78 a	10.56 ± 0.39 a	15.07 ± 0.29 a	10.67 ± 0.28 a	0.39 ± 0.03 a	27.66 ± 1.45 a	5.83 ± 0.19 a	1.14 ± 0.04 a
2021	MA	206.70 ± 8.00 b	9.75 ± 0.41 b	14.71 ± 0.35 a	10.18 ± 0.22 b	0.41 ± 0.07 a	25.02 ± 3.85 a	5.49 ± 0.19 a	4.75 ± 0.18 b
	IR	229.79 ± 8.28 a	10.69 ± 0.35 a	15.01 ± 0.18 a	10.68 ± 0.12 a	0.39 ± 0.04 a	27.35 ± 2.94 a	5.92 ± 0.08 a	5.29 ± 0.19 a

MA- monocropped apples; IR- intercropped apples. The same letters in the same column indicated no significant difference at 0.05 level in Duncan's analysis.

4. Discussion

4.1. Soil Moisture Content

Soil moisture is a key factor limiting plant growth in semi-arid regions [25]. It has been suggested that grass planting can improve soil water retention and increase soil moisture content [26], and it has also been suggested that grass planting can promote water depletion in orchards, which is detrimental to fruit tree growth [27]. Intercropping is a means of providing sustainable and productive agriculture [28]. Intercropping ryegrass with apples is mainly influenced by the combined effects of transpiration, soil evaporation, and irrigation of apple trees and cover crops. Ryegrass increases ground cover, which can reduce ineffective evaporation of soil surface water and has a moderating effect on the orchard soil water content [29]. In this study, the soil moisture content was measured continuously in a zero to 60 cm soil layer to study the effect of the different cropping patterns on the soil moisture dynamics in the orchard. It was found that when apple was intercropped with ryegrass, the soil water content increased with the increase in soil depth; the change in the soil water content in the zero to 40 cm layer was the most prominent, mainly because inter-row grass planting can reduce soil evaporation and plays a role in water retention, which is consistent with the results of Sun et al. [10].

In general, the degree of water uptake by different soil layers depends on the amount of available water in the soil profile [30]. Spatial variability of soil water in orchards exists mainly because of the differences in the degree of soil water utilization by apple trees caused by differences in the spatial distribution of their root systems. Planting ryegrass between apple tree rows can effectively reduce soil water evaporation, increase soil water content between apple tree rows, and increase the use of soil water between rows by apple trees. At the same time, ryegrass transpiration and surface evaporation in grassy orchards were greater than those in clear-cut orchards, producing a water competition effect [31].

4.2. Soil Salinity

Soil salinization is significantly harmful to the ecological environment, agricultural production, engineering construction, and soil and water resources, especially in the northern arid regions of China and the western irrigated agricultural areas; this has become an important factor limiting the sustainable development of the region [32]. It was found that intercropping salt-tolerant plants in cotton fields with sub-membrane drip irrigation can reduce soil salinity, increase water content, increase cotton yield, and improve water use efficiency [33]. Li et al. planted alfalfa on saline land in the Chidamu Basin and found that the total salt content of zero to 30 cm soil decreased from 1.52% before planting to 0.13%, and the salt phenology was no longer obvious [34].

In this study, the Na^+ and total salt contents in apples intercropped with ryegrass and monocropped apples were determined. Apple intercropped with ryegrass had a significant desalination effect on the zero to 40 cm soil layer, while there was salt enrichment in the 40–60 cm soil layer. This is because the root system of the crop disrupts the original structure of the soil and increases the permeability of the soil so that the salts are transported downward; the result is consistent with the first hypothesis that apple-ryegrass intercropping systems can have a beneficial effect on salinity management by changing the concentrations of salt ions in the soil. Different plants impact soil salt differently, which can also affect the salt ion content [35]. Alfalfa grass was able to significantly reduce the total soluble salts in the 0–40 cm soil layer of coastal saline soils, with a desalination rate of 65.5%, while the bottom layer changed less [36], which is consistent with the results of this study. In this study, we have only investigated the desalination effect of various patterns on 0–60cm soils. In the future, we should focus on the desalination effect of various patterns on deeper soils in order to facilitate other soil improvement measures to reduce salt and improve soil fertility.

4.3. Photosynthesis

Daily changes in plant photosynthesis show different trends depending on the growing environment. A date/wheat and cotton complex system improved the canopy structure of intercropped crops by reasonably optimizing the crop layout, which in turn improved the photosynthetic rate of the crops and increased their light interception and light energy utilization [37]. The apple/wheat complex system increased light intensity and improved light energy utilization [38]. The present study showed that the inhibition of photosynthesis in apple leaves by high temperature and strong light was significantly alleviated, and the utilization of strong light was improved, the same as the findings of Yang et al. [39]. The net photosynthetic rate and stomatal conductance of all intercropped apple leaves were higher than those of monocropped apples, which is generally consistent with the findings of Yang et al. [40]. The transpiration rate is an important physiological indicator of plant water metabolism. The present study showed that intercropping ryegrass with apple significantly increased the transpiration rate of the apple leaves, which may be that sand and dust blocked the stomata of apple leaves and thus reduced the transpiration rate of the apple leaves. The effect of sand and dust on monocropped apples was greater than that on intercropped apples. The result is consistent with the second hypothesis that apple-ryegrass intercropping has a positive effect on the reduction of dust damage in apple leaves. Intercropping significantly reduced the intercellular CO_2 concentration of apple leaves, which is consistent with the findings of Hu et al. [41].

4.4. Microclimate

The Microclimate is the main environmental factor affecting the growth and development of crops, not only photosynthesis and the growth and development of crops but the change in the soil structure, nitrogen migration and transformation, and microbial diversity. Intercropping changes the natural conditions such as the field temperature, humidity, and light, forming a microclimate environment favorable to crop growth and development and improving the crop yield. Furthermore, orchard grass cultivation can regulate orchard temperature and humidity, improve the orchard microclimate, improve the soil organic matter, water retention, water storage capacity, and enhance fruit quality and yield, thus forming balanced orchard ecosystems [42].

Intercropping also reduced wind speed and had a significant wind protection effect. Date palm intercropped with cotton and alfalfa resulted in significantly lower wind speed due to the planting of the date palm trees, and the wind protection effect of date palm intercropped with alfalfa was lower than that of intercropped cotton in the case of high winds, but both were greater than that of the monocrop system [43]. This is due to the relatively small row spacing of date palm trees, which increases the wind friction and thus reduces the wind braking force and improves the wind protection effect. In addition, intercropping reduces temperature and increases humidity. Apple intercropping with white clover produced a suitable climate for fruit tree growth, improved resource utilization, and increased fruit tree yield due to the reduction of the lower surface and subsurface temperatures and increased humidity [44]. The present study showed that intercropping significantly reduced the temperature and wind speed, increased the relative air humidity, and enhanced the wind protection effectiveness at different fertility stages, which is generally consistent with the results of Mao et al. [45] and Moreira et al. [46].

4.5. Fruit Tree Growth Indicators, Yield and Fruit Quality

During apple growth and development, the orchard microclimate environment and photosynthesis are closely related to fruit tree growth indicators and quality, and intercropping with ryegrass in orchards significantly improved the orchard microclimate environment and fruit tree growth indicators, thus improving the apple fruit quality. Grassing improved the ecological environment of the orchard and increased leaf photosynthesis, thereby promoting tree growth [15], which is consistent with the results of this study. In addition, low concentrations of salinity can promote plant growth, while high concentrations of saline stress inhibit plant growth and can lead to death in severe cases. The growth of fruit trees under saline stress can be used as indicators to judge the salinity tolerance of fruit trees [47]. Both apple plant height and stem thickness decreased gradually with increasing stress concentration. Some researchers have suggested that fruit tree and grass intercropping can reduce the occurrence of fruit diseases and thus improve the quality of their processed products [48,49]. The present study showed that intercropping significantly increased the single fruit weight, fruit hardness, and yield of apples, which is consistent with the results of Jia et al. [50]. The significant increase in the single fruit weight of intercropped apples may be related to the increase in soil nutrients and the water content; the increase in fruit hardness may be related to the increased uptake of soil mineral elements by fruit trees; the increase in the sugar-acid ratio may be related to the decrease in the titratable acid content and the increase in soluble solids. It can be seen that the improvement in apple quality is directly related to intercropping. The result is consistent with the second hypothesis that apple-ryegrass intercropping has a positive effect on yield and quality.

5. Conclusions

In this study, it was found that apple-ryegrass intercropping affected the soil water, soil salinity, photosynthetic index, fruit tree growth indicators, yield, and quality. The soil water content, net photosynthetic rate, transpiration rate, stomatal conductance, and fruit tree growth indicators in the intercropping system were higher than those under monocropping. The intercellular CO_2 concentration, soil Na^+, and total soil content in the intercropping system were lower than those under monocropping. Intercropping significantly improved the orchard microclimate, increasing fruit yield and improving fruit quality. Thus, intercropping should be properly promoted to improve soil salinization, crop yield and quality.

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