Pak. J. Bot., 57(3): DOI: http://dx.doi.org/10.30848/PJB2025-3(31)

STUDY ON WATER RETENTION AGENT AND BIOCHAR APPLICATION BASED ON SOIL CONSERVATION IN KARST ORCHARDS

TE XU[1*], XIAOTONG FANG[1], QIANJU WANG[1], MAN LONG[2], TENG YUAN[2] AND CHUN XIAO[2]

[1]Guizhou Fruit Institute, Guizhou Academy of Agricultural Sciences, Guiyang, Guizhou Province 550006, China
[2]Liupanshui Shuicheng District Kiwifruit Research Institute, Guizhou Province 553600, China
[*]Corresponding author's email: lee_hsue@163.com

Abstract

Karst mountain region presents a formidable challenge for agriculture, given its intricate geological formations and distinctive soil characteristics. The soil in this region exhibits high porosity, facilitating rapid water infiltration and subsequent moisture loss. In this study, the effects of compound water retention agents on soil structure and fruit tree photosynthesis in Karst mountain was investigated by setting different application rates of water retention agents and biochar.The findings indicated a significant improvement in soil structure, water regulation capacity, and plant photosynthetic growth in the soil treated with water retention agents compared to the control group (referred to as ck, set without water retention agents). After the application of water retention agents, the soil's capacity for retaining and transporting water was significantly enhanced, thereby improving the growth environment and promoting crop growth. Based on soil regulation and plant growth perspectives, an application rate of 95 g/m³ PAM or 122 g/m³ KPAA was determined to be the most suitable under the experimental conditions.

Key words: Karst Mountain; Water retention agent; Plant; Soil nutrients; Soil structure.

Introduction

A water retention agent is a highly absorbent resin that has a solid ability to repeatedly absorb and release water (Elshafie & Camele, 2021; Xi & Zhang, 2021). They have been widely used in agriculture, forestry, landscaping projects, slope protection, and ecological restoration (Li *et al*., 2019; Bucak & Sahin, 2022). As China's infrastructure construction advances, the construction of railways and roads in most areas will result in many exposed rocky slopes. These activities not only destroy vegetation and soil but also tend to cause soil erosion, leading to disasters such as slope failures and debris flows (Yang *et al*., 2021; Liu *et al*., 2023). Therefore, revegetation of rocky slopes is essential. The main difficulties in the ecological restoration of rocky slopes include the hardness of the rock surface, their poor water-holding properties, and the lack of soil and water for plant growth (Huang *et al*., 2022). Most rocky slopes are steep, and rainfall erosion can lead to strong runoff and high runoff rates, with the consequent removal of nutrients from the soil occurring (Huang *et al*., 2022). Therefore, the critical point in achieving the ecological restoration of rocky slopes is to improve soil water and nutrient conditions (Brannigan *et al*., 2022). The application of water retention agents in artificial vegetation restoration on rocky slopes can significantly increase the water content of the soil and reduce soil water loss and the loss of soil nutrients with runoff, thus achieving water and fertility retention (Jahan & Mahallati, 2020; Saha *et al*., 2020; Fang, 2021). At present, research on the application of water retention agents mainly focuses on soil physical and chemical properties, and soil moisture content in arid and semi-arid areas (Verma *et al*., 2019; Tahoun *et al*., 2022; Xerdiman *et al*., 2022; Zhang *et al*., 2023; Xu *et al*., 2023). Research on the impact of water-retaining agents on plant growth also primarily centers around the germination of grass seeds and the effectiveness of turf establishment (Su *et al*., 2017; Pramthawee *et al*., 2017; Zhou *et al*., 2021; Wei *et al*., 2022), However, there is a paucity of research on the utilization of water-retaining agents in orchard production, particularly regarding their impact on soil moisture retention and the water consumption of fruit trees.

The karst landscape in southern China, centered around the Guizhou Plateau, represents the world's largest exposed area of concentrated karst formations (Haiting, 2022). Karst Mountain is an important agricultural region that is known for its complex geological formations and unique soil characteristics (Xiaofei, 2024). In this ecological area, vegetation decay is frequently attributed to the process of rocky desertification, exacerbating surface rock exposure and diminishing the land's water conservation function, ultimately leading to ecological and economic impoverishment. To enhance the local ecological environment and facilitate the harmonious development of ecology and economy, the three-dimensional agricultural model focusing on fruit tree cultivation has emerged as a pivotal approach for sustainable ecological restoration in karst mining areas, yielding comprehensive value through ecological products. Furthermore, as an outcome of mine ecological restoration efforts, the growth of ecological products is influenced by environmental factors, with the eco-industry transitioning from resource consumption to technology efficiency. Particularly within a climate characterized by uneven spatial and temporal water distribution, enhancing soil moisture retention in orchards and optimizing plant water usage are imperative for sustainable production. The aim of this essay is to examine the effects of compound water retention agents on soil structure and fruit tree photosynthesis in Karst Mountain.

Material and Methods

Materials: Polyacrylamide (PAM), identified by its CAS number 9003-05-8 and a molecular formula (C3H5NO)n, is a linear organic polymer capable of adsorbing suspended particles in water and serving as a linking bridge between particles. In the fields of agriculture and forestry, PAM is commonly utilized as a water retention agent or in combination with other substances to enhance soil quality. Specifically, this study predominantly employed PAM particle sized at 2~4mm.

Potassium polyacrylate (KPAA), identified by its CAS number 25608-12-2 and a molecular formula $(C_3H_6O_2)_n \cdot (C_3H_5KO_2)_m$, exhibits potassium fertilizer properties in contrast to traditional sodium polyacrylate. KPAA is commonly employed as a water retention agent in agriculture and forestry to enhance soil structure. This study, primarily utilized KPAA with the specified particle sized 2~4mm for its intended purposes.

Experimental area: The experiment was conducted in a kiwifruit orchard located in Shuicheng District, Liupanshui City (104°58′49″E, 26°24′21.54″N, altitude 1118 meters). In the orchard, soil samples within the depth range of 0 - 30 cm were collected by means of a soil auger following a five-point sampling approach, with a total mass ranging from 5 to 8 kg. After being air-dried, coarse roots and small stones were eliminated, and the soil was evenly divided into five 500-g aliquots. One aliquot of the original soil sample was designated as the control group, while the remaining four aliquots were uniformly mixed and stirred with water retention agents of PAM and KPAA at diverse ratios, ensuring that the contents of the water retention agents in the soil were 0.1%, 0.3%, 0.5%, and 1% respectively. The treated soil samples were partitioned into 250-g portions using the quartering method, thoroughly moistened with a watering can, air-dried once more, and the variations in soil aggregates were determined through the wet-sieving method.

A random sample of female kiwifruit trees with similar growth conditions and ages were selected for the experiment. Four trenches, each 40cm wide and located at a distance of 40cm from the tree trunk, were excavated around each tree. Varying ratios of PAM and KPAA (25g, 40g, 55g, 70g, and 85g) were incorporated into the soil in these trenches. The mixture was backfilled to a depth of 30cm and irrigated until the soil reached an 80% fully field capacity. Subsequently, irrigation was provided through natural rainfall. Soil samples were collected after the first irrigation for analysis of soil aggregates. Green shadows in Fig. 1 indicate the location of the trenches.

Based on the influence of various polymer materials on soil aggregates, appropriate ratios of polymer materials were identified. In conjunction with autumnal application of biochar, 5kg of mushroom substrate biochar was administered per tree, and the optimal utilization of water retention agents was determined based on the regulation of soil structure and water management in the orchard.

Soil aggregates

$$Wgi = \sum_{j} Wgj \tag{1}$$

Wgi is the corresponding mass percentage (%), mj is the mass of a certain level of water-stable aggregates in the air-dried state, and Wgj is the corresponding mass percentage (%).

Field water-holding capacity of soil

$$\theta_f(\%) = 100 \times (M - M\text{d}) / (M_\text{d} - Mo) \tag{2}$$

M - the weight (g) of the moist soil on the humidified sand after being placed for 24 hours, Md - the weight (g) of the dried soil and the ring cutter, Mo - the weight (g) of the ring cutter.

Soil bulk density

$$d_v = (M\text{d} - M_o) / V \tag{3}$$

dv - soil bulk density (g·cm-3), Md - the weight (g) of the dried soil and the ring cutter, Mo - the weight (g) of the ring cutter, V - the volume (cm3) of the ring cutter.

Soil capillary porosity and total porosity

The ring cutter method is used for determination, with the formulas:

Soil capillary porosity (%) = (M1-M2)/V×100 (4)
Total porosity (%) = (M2-M3)/V×100 (5)

where M1 is the weight (g) of the ring cutter and moist soil after being soaked in a water dish for 8 hours, M2 is the weight (g) of the ring cutter and soil after being soaked twice until the filter paper above the ring cutter is fully moistened, and then dried to constant weight at 105°C, M3, V is the volume (cm3) of the ring cutter.

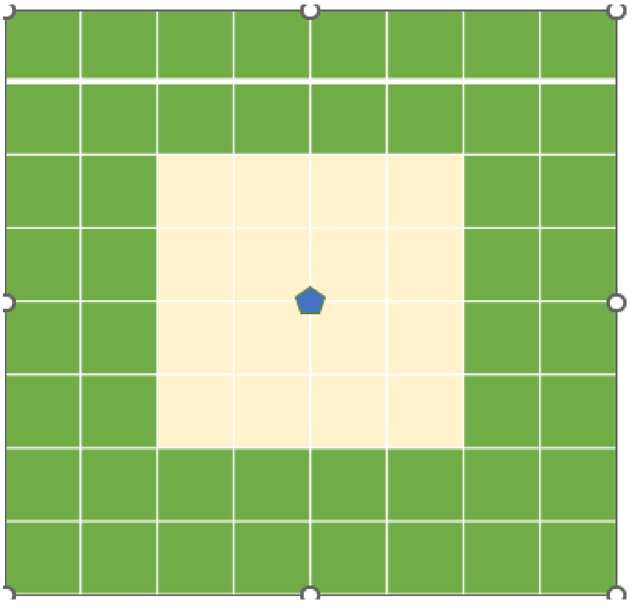

Fig. 1. Schematic representation of the utilization of polyacrylic acid potassium water retention agent in the strip furrow.

Capillary water capacity

Capillary water capacity = Capillary porosity / Soil bulk density (6)

Measurement of soil volumetric water content

The soil volumetric water content (SWC, % v/v) was determined using Time Domain Reflectometry (TDR) technology (DELTA-T DEVICES Ltd., Cambridge, CB, UK).

Measurement of instantaneous photosynthetic parameters of plant leaves: During the stages of flowering, fruit swelling, and fruit ripening, under stable environmental conditions on a typical sunny day between 9:00-11:00, the plant's net photosynthetic rate, transpiration rate, and other photosynthetic physiological parameters are measured using a LI-COR 6400XT portable photosynthesis system (LICOR, Lincoln, NE, USA). The instantaneous water use efficiency (WUE) of leaves is calculated by the formula below:

$$WUE = Pn / Tr \quad (7)$$

Instantaneous water use efficiency (μmol·mmol^{-1}), net photosynthetic rate (μmol·m^{-2}·s^{-1}), transpiration rate (mmol·m^{-2}·s^{-1}).

Statistical Analysis

The data were processed and visualized using Microsoft Excel 2019, with variables described in terms of means and standard deviations. One-way analysis of variance (ANOVA) was conducted using SPSS 22.0 software, and treatment comparisons were assessed through Duncan's multiple range test at the 0.05 significance level.

Results and Discussion

Effect of water retention agents on soil structure

Table 1 presents the alterations in soil aggregate composition following the application of varying ratios of PAM and KPAA (KPAA) to the soil. Overall, the content of wind-dried aggregates larger than 2mm was the highest, averaging 43% to 44%. As the ratio of the two soil conditioners increased, there was a significant decrease in the proportion of microaggregates with a size less than 0.25mm, indicating that both soil conditioners can effectively promote soil aggregate structure formation. Additionally, when the ratio of PAM or KPAA was less than 0.5%, KPAA demonstrated greater effectiveness in promoting soil aggregate formation. It is noteworthy that an increase in PAM ratio led to a significant rise in large aggregates (>2mm), while there was a decline in aggregates with sizes between 0.25 and 2mm after the PAM ratio exceeded 0.5%. Furthermore, although this study did not observe any phenomenon of decreased aggregate formation with increasing ratio, it still suggests that careful control over proportions is necessary when utilizing PAM for improving soil structure.

Table 1. Effect of water retention agents on the composition of soil agglomerates.

Trail	Distribution of agglomerates at all levels (%)				
	＞2mm	2~1mm	1~0.5mm	0.5~0.25mm	＜0.25mm
CK	43.51 ± 0.36b	11.94 ± 0.36a	17.11 ± 0.35a	7.06 ± 0.18a	20.36 ± 0.19a
0.1% PAM	43.56 ± 0.11b	12.09 ± 0.33a	17.23 ± 0.41a	7.03 ± 0.18a	20.09 ± 0.59a
0.3% PAM	43.79 ± 0.21b	12.32 ± 0.08a	17.36 ± 0.29a	7.29 ± 0.11a	19.24 ± 0.47b
0.5% PAM	44.25 ± 1.26a	12.25 ± 0.51a	17.33 ± 0.37a	7.18 ± 0.83a	18.89 ± 0.64b
1% PAM	44.75 ± 1.29a	12.12 ± 0.78a	17.22 ± 1.14a	7.06 ± 0.59a	18.85 ± 1.11b
0.1% KPAA	43.69 ± 0.22b	12.10 ± 0.26a	17.20 ± 0.17a	7.05 ± 0.19a	20.15 ± 0.43a
0.3% KPAA	43.93 ± 0.45ab	12.12 ± 0.31a	17.21 ± 0.49a	7.06 ± 0.15a	19.28 ± 0.82b
0.5% KPAA	44.29 ± 0.63a	12.23 ± 0.53a	17.33 ± 0.32a	7.16 ± 0.19a	18.85 ± 0.67b
1% KPAA	44.73 ± 0.76a	12.33 ± 0.47a	17.35 ± 0.39a	7.30 ± 0.28a	18.89 ± 0.32b

Note: Lowercase letters a, b, c... denote the variation in soil aggregate proportion within the same grade at a significance level of 0.05 under different water retention agent dosages

Table 2. Effect of water retention agents on the composition of soil agglomerates.

Trial	Distribution of agglomerates at all levels（%）				
	＞2mm	2~1mm	1~0.5mm	0.5~0.25mm	＜0.25mm
CK	43.51 ± 0.36c	11.94 ± 0.36a	17.11 ± 0.35ab	7.06 ± 0.18b	20.36 ± 0.19a
25g PAM	43.94 ± 0.47c	12.10 ± 0.82a	17.31 ± 0.32a	7.42 ± 0.85a	18.65 ± 0.28b
40g PAM	44.06 ± 0.27c	12.44 ± 0.78a	17.66 ± 0.78a	7.20 ± 0.48b	18.37 ± 0.83b
55g PAM	51.52 ± 0.26a	12.60 ± 0.29a	17.21 ± 0.55ab	6.94 ± 0.78b	11.40 ± 0.78d
70g PAM	50.68 ± 0.23b	12.16 ± 0.58a	16.32 ± 0.47b	6.81 ± 0.38b	13.87 ± 0.29c
85g PAM	43.27 ± 0.58c	11.92 ± 0.96a	17.17 ± 0.87ab	7.08 ± 0.26b	20.34 ± 0.73a
25g KPAA	43.27 ± 0.73c	12.03 ± 1.12a	17.19 ± 0.28ab	7.32 ± 1.15a	20.19 ± 0.37a
40g KPAA	43.98 ± 0.51c	12.38 ± 0.93a	17.35 ± 0.99a	7.44 ± 0.78a	18.75 ± 1.03b
55g KPAA	44.12 ± 0.66c	12.54 ± 1.29a	17.68 ± 1.55a	7.28 ± 0.59ab	18.38 ± 1.16b
70g KPAA	51.74 ± 0.11a	12.64 ± 0.33a	17.21 ± 0.41ab	6.94 ± 0.18b	11.46 ± 0.59d
85g KPAA	50.68 ± 0.70b	12.26 ± 1.06a	16.32 ± 0.95b	6.83 ± 0.76b	13.91 ± 1.06c

Note: Lowercase letters a, b, c... denote the variation in soil aggregate proportion within the same grade at a significance level of 0.05 under different water retention agent dosages

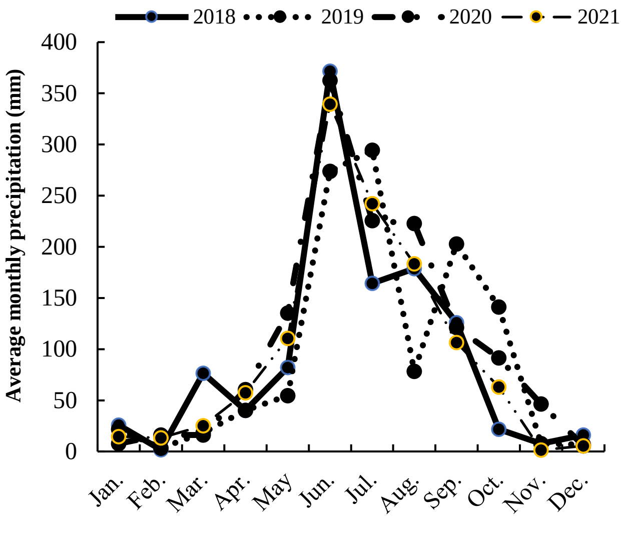

Fig. 2. Average monthly precipitation for 2018~2021

Table 2 presents the alterations in soil aggregate composition following the application of varying densities of PAM and KPAA within tree disk trenches. According to the application method, water retention agents with densitiesof 43 g/m³, 69g/m³, 95g/m³, 122g/m³ and 148 g/m³ were sequentially incorporated into the top 30 cm of soil within the vertical plane of tree disk. The experiment revealed a significant increase in the proportion of large aggregates when applying 55g to 75g of PAM, resulting in a density of 95~122 g/m³ of water retention agents in the tree disk soil. However, upon increasing density to 148 g/m³ (applied at 85g), there was a notable decrease in aggregates sized at or above 1 mm, while an increase was observed in aggregates sized below 1 mm. This suggests that excessive use of PAM-type water retention agents is not conducive to the formation of large aggregates.

Similarly, the application of 70g of KPAA water retention agents led to a significant increase in the proportion of large aggregates when the density reached approximately 122 g/m³ in the tree disk soil. However, with an increase in density to 148 g/m³ (applied at 85g), there was a slight decrease in the proportion of large aggregates, highlighting the importance of precise proportion control when utilizing KPAA for soil structure enhancement. Notably, in this experiment, varying densities of KPAA water retention agents did not have a significant impact on the formation of aggregates within the size range of 0.25~2mm, which may be attributed to the particle size utilized in this study.

The findings of this experiment suggest that, in comparison to the treatment without water retention agent application, increasing the dosage of water retention agents can significantly enhance the structure of large aggregates, soil porosity, and soil capillary water holding capacity. This indicates that the utilization of water retention agents can effectively improve slope soil structure. Some research has indicated that the optimal application amount of water retention agents varies for different crops, and it does not simply adhere to a "more is better" pattern; beyond a certain threshold, its impact has been observed to plateau (Zhou *et al*., 2021).

Effect of water retention agent with biochar application on soil physical structure and water regulation

In the previous section examining the impact of varying water retention agent ratios on soil aggregation, it was observed that PAM and KPAA demonstrated significant enhancements to soil aggregation structure at plant application densities of 95 g/m³ and 122 g/m³, respectively. Consequently, in November 2021, the study implemented the aforementioned application densities and administered 5kg/plant of bacterial straw-based biochar to kiwi fruit trees post-harvesting for further investigation into the effects of different water retention agents on soil aggregation structure and water regulation. The ck treatment denotes the conventional application of 5kg/plant.

Table 3 demonstrates that the application of biochar alone did not exert a significant impact on soil aggregation structure. However, both methods of biochar application notably facilitated the formation of large soil aggregates, particularly those exceeding 2mm in size. Furthermore, when considering Table 2, it was observed that the promotion effect on large soil aggregates was either non-significant or even diminished following biochar application, suggesting that water retention agents play a pivotal role in enhancing soil structure. Additionally, KPAA exhibited superior efficacy in promoting the formation of large soil aggregates.

After the application of various water retention agents, Table 4 reveals a significant decrease in soil bulk density compared to conventional biochar application. Additionally, there were varying degrees of increase in total porosity, capillary porosity, field capacity, and capillary water holding capacity. These findings suggest that the addition of water retention agents effectively enhances soil permeability and water retention capacity. Notably, PAM demonstrated slightly superior effects compared to KPAA.

Effect of water retention agents on soil water content of fruit trees in different growth periods

During the period from 2018 to 2021, the annual precipitation trend in Shuicheng District exhibited a decrease during the budding and flowering period of kiwifruit trees, followed by an increase during the fruit expansion period, reaching its peak during the fruit ripening period, and then decreasing. Therefore, considering the growth stages of the fruit trees, a single artificial irrigation was conducted after applying water retention agent and biochar to saturate soil water content to 80% of field capacity, with no further irrigation performed. The variations in soil moisture content during the flowering, fruit expansion, and ripening periods of kiwifruit trees were monitored. The findings are presented in Figure 3.

Figure 3 illustrates that there were no significant differences in soil moisture content among the treatments during the full irrigation and flowering periods. The soil experienced continuous water loss due to weak precipitation replenishment until the onset of the flowering period. As the fruit development stage commenced and precipitation replenishment gradually increased, soil moisture content showed variations among the treatments. The water holding capacity of the soil was observed to be in the order of PAM + biochar > KPAA + biochar > conventional biochar application, reaching its peak during early fruit expansion. From this stage to fruit ripening, a gradual decrease in precipitation and water consumption led to a decline in soil moisture content, with varying degrees of water loss under each treatment reflecting differences in soil water transport capacity: PAM + biochar > KPAA + biochar > conventional biochar application.

Recent research has demonstrated that the application of water retention agents significantly enhances soil quality and promotes water conservation through two primary mechanisms. Firstly, when applied to the soil, water retention agents have the capacity to absorb water and gradually expand, integrating with the soil to form a protective film. This process effectively mitigates the impact of rainwater on the soil surface, thereby safeguarding it from erosion (Zhang *et al*., 2020; Yan *et al*., 2021). Secondly, a judicious application of water retention agents exerts a binding effect on the soil, leading to the adsorption of micro-aggregates around these agents. Consequently, this results in larger aggregates and an increased capillary water holding capacity, ultimately reducing soil loss due to runoff and minimizing water loss as a result of erosion (Mechtcherine *et al*., 2021). Furthermore, studies have indicated that in mining areas, these agents can enhance soil fertility by intercepting water and significantly increasing levels of effective nitrogen, phosphorus, potassium as well as organic matter content (Rezashateri *et al*., 2016; Sweijen *et al*., 2017).

Effect of water retention agents on leaf photosynthesis of fruit trees during different growth periods: In order to further investigate the impact of various water retention agents on the growth of fruit trees, we conducted an observation of the photosynthetic physiology of fruit tree leaves during the flowering period, fruit swelling period, and maturity period. The results are presented in the figure below.

During the transition from flowering to maturity, fruit tree leaves exhibited an overall increase in net photosynthetic rate and transpiration rate, with the KPAA + biochar treatment outperforming the PAM + biochar treatment, and the conventional biochar treatment showing the lowest performance. Throughout the entire growth period, the disparity in net photosynthetic rate and transpiration rate among treatments was most pronounced during fruit swelling, with increases of 25.47%, 46.24%, 12.14%, and 36.92% for the KPAA + biochar and PAM + biochar treatments compared to single biochar treatment.

Table 3. Effect of different application methods on the composition of soil agglomerates.

Trial	Distribution of agglomerates at all levels (%)				
	＞2mm	2~1mm	1~0.5mm	0.5~0.25mm	＜0.25mm
CK (Biochar)	43.66 ± 0.27c	12.02 ± 0.31a	17.08 ± 0.36a	7.11 ± 0.21b	20.12 ± 0.21a
PAM (95 g/m³) + Biochar	48.41 ± 0.21b	12.66 ± 0.08a	16.83 ± 0.29a	7.68 ± 0.11a	14.41 ± 0.47b
KPAA (122 g/m³) + Biochar	51.74 ± 0.11a	12.64 ± 0.33a	17.21 ± 0.41a	6.94 ± 0.18b	11.46 ± 0.59c

Note: Lowercase letters a, b, c... denote the variation in soil aggregate proportion within the same grade at a significance level of 0.05 under different water retention agent dosages

Table 4. Effect of different application methods on soil physical properties.

Trial	Soil capacity	Soil total porosity	Soil pore porosity	Soil field water holding capacity	Soil capillary water holding capacity
CK (Biochar)	1.31 ± 0.09a	55.75 ± 0.98a	47.46 ± 1.33a	36.80 ± 1.18a	36.54 ± 1.39b
PAM (95 g/m³) + Biochar	1.10 ± 0.07b	59.31 ± 0.85a	51.63 ± 1. 92a	38.90 ± 1.96a	47.08 ± 1.47a
KPAA (122 g/m³) + Biochar	1.13 ± 0.13b	58.85 ± 0.69a	51.05 ± 0.91a	38.65 ± 0.98a	45.43 ± 0.86a

Note: Lowercase letters a, b, c... denote the variations in detection parameters of identical soil samples at a significance level of 0.05 when subjected to varying dosages of water retention agent treatment

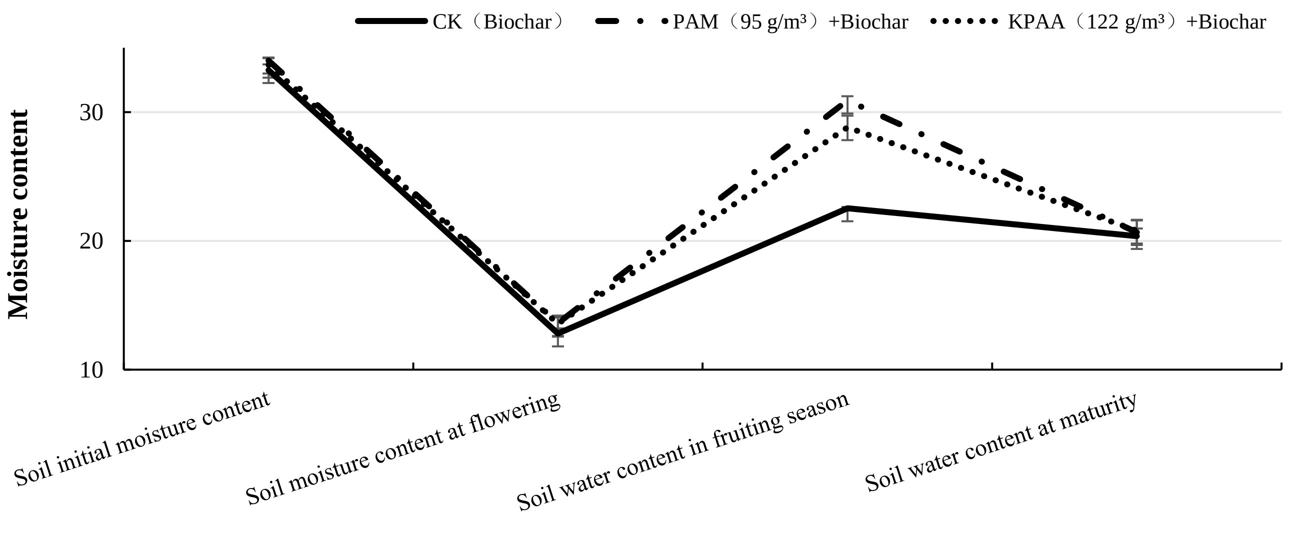

Fig. 3. Soil water content of fruit trees in different growth periods.

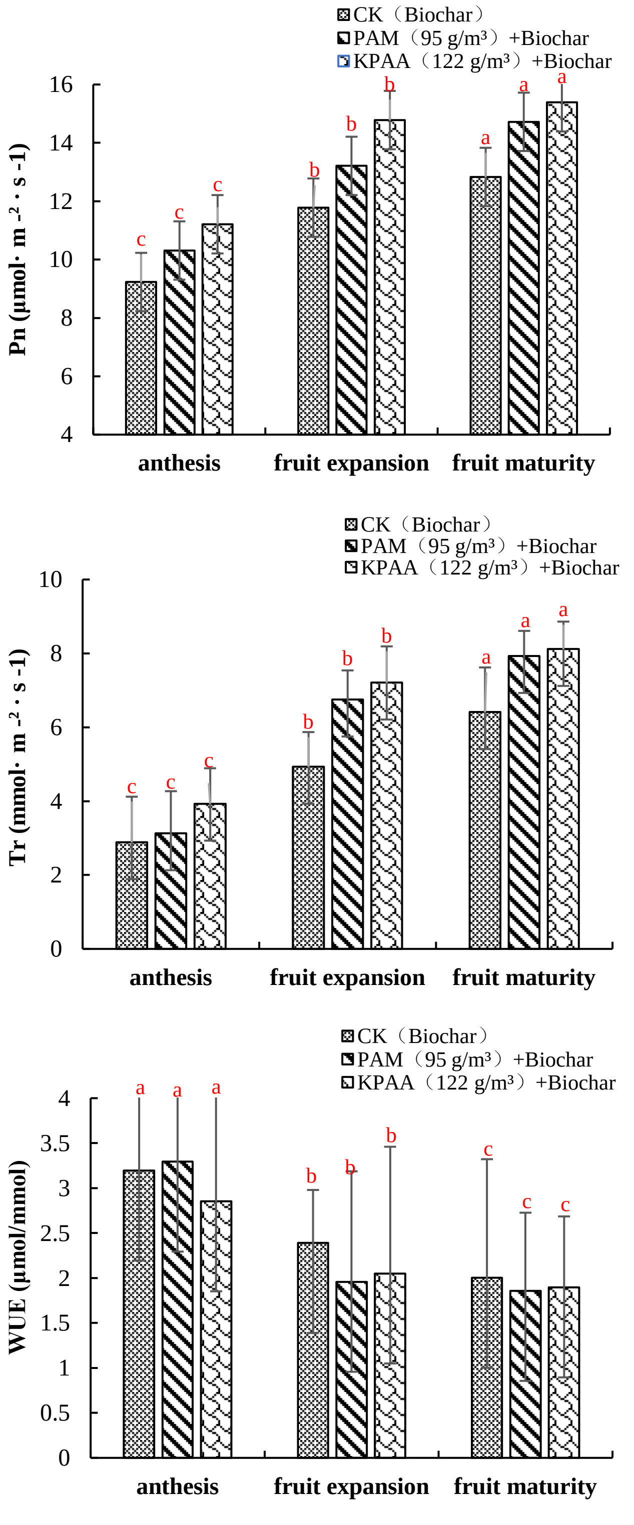

Fig. 4. Net photosynthetic rate (Pn), Transpiration rate (Tr), water use efficiency (WUE) of fruit tree leaves in each period.

The water use efficiency of plants reflects the accumulation of dry matter after transpiration, which can elucidate the relationship between plant metabolism and water use efficiency. Numerous studies have investigated alterations in plant water use efficiency, revealing that it may increase under water stress, particularly at the leaf level (Mohammadpour & Sadeghi, 2020; Song *et al*., 2022). In this study, apart from observing higher water use efficiency with PAM treatment during the flowering period, the application of water retention agents during the fruit swelling stage resulted in varying degrees of reduction in leaf water use efficiency. This suggests that under consistent irrigation conditions, the utilization of water retention agents enhances soil's moisture availability, enabling fruit trees to withstand high evaporation demand during hot summers by maintaining a lower water use efficiency.

Studies have demonstrated that the application of a water retention agent to soil results in rapid absorption of water from the soil, leading to a reduction in deep infiltration losses. Subsequently, the absorbed water is gradually released to plants during periods of drought, thereby enhancing the efficiency of soil water utilization and promoting the development of above-ground plant parts (Tomášková *et al*., 2020; Liang *et al*., 2021). Furthermore, the use of water retention agents can improve the soil's capacity for holding moisture, ultimately contributing to increased plant survival rates and vitality (Rizwan *et al*., 2021). In our experiment, we also observed periodic changes in soil water content with fruit tree growth. The difference between groups was found to be significant ($p<0.05$) when compared with the control group (ck), showing an increasing trend with higher dosages of water retention agent. This can be attributed to improved maintenance of optimal moisture conditions. Additionally, there was a significant increase in retained water by the agents within each group ($p<0.05$), potentially promoting plant growth.

Conclusion

To enhance the soil structure and water regulation in kiwifruit orchards located in karst mining areas, soil entropy improvement was implemented to create an optimal soil water environment for fruit trees during dry seasons with limited access to engineering water sources. the combination of PAM and KPAA water retention agents with biochar can be selected. Specifically, the application of 95 g/m³ to 122 g/m³ of PAM and 122 g/m³ to 148 g/m³ of KPAA alone has been shown to significantly enhance soil aggregate formation. While conventional biochar has a weaker promotion effect on soil aggregate formation, its effectiveness can be improved by combining it with either 95 g/m³ of PAM or 122 g/m³ of KPAA. This combined approach can increase soil air permeability and water infiltration, enhance soil water-holding capacity and water transport capacity, promote fruit tree photosynthesis, and alleviate water stress.

In order to achieve a balanced development of ecological and economic benefits in karst mountain orchard practice, it is essential to consider not only the production improvement effect but also the economic cost. The cost of PAM used in this experiment was 0.03CNY/g, the cost of KPAA was 0.02CNY/g, and the cost of biochar was 1.3CNY/kg. To achieve optimal soil improvement effects, the cost per unit volume for single use of PAM ranges from 2.85CNY/m3 to 3.66CNY/m^3, while for KPAA it ranges from 2.44CNY/m3 to 2.96CNY/m^3.

Taking kiwi fruit orchard in the test area as an example, the combined cost of using PAM and KPAA with biochar was found to be 9.35CNY/plant and 8.94CNY/plant respectively.

Research results indicate that applying a rate of 122 g/m^3 KPAA significantly improved soil agglomeration structure and plant photosynthesis at a relatively higher material consumption compared to using 95g/m^3 PAM (costing only 0.41 CNY per plant). Therefore, considering economic costs, application of KPAA at a rate of 122 g/m^3 can better achieve synergistic improvements in ecological sustainable production and soil environment in karst mountain orchard production.

Acknowledgments

The authors extend their gratitude to the editor and reviewers for their valuable feedback, which has enhanced the quality of this paper. This research was supported by the Youth Science and Technology Innovation Research Team Project of the Guizhou Fruit Institute and the Youth Research Grant from the Guizhou Academy of Agricultural Sciences.

References

Brannigan, N., D. Mullan, K. Vandaele, C. Graham, J. McKinley and J. Meneely. 2022. Modelling soil erosion by water under future climate change: Addressing methodological gaps. *Catena*, 216: 106403.

Bucak, C.D. and M.O. Sahin. 2022. Super-flexible, moldable, injectable, self-healing PVA/B/CMC hydrogels synthesis and characterization, as potential water-retaining agent in agriculture. *Poly. Bull*., 80(6): 6591-6608.

Elshafie, H.S. and I. Camele. 2021. Applications of absorbent polymers for sustainable plant protection and crop yield. *Sustainability*, 13(6): 3253.

Fang, H. 2021. Effect of soil conservation measures and slope on runoff, soil, TN, and TP losses from cultivated lands in northern China. *Ecol. Indicat*., 126: 107677.

Haiting, S., Z. Liu, K. Xiong and L. Li. 2022. A Study Revelation on Market and Value-Realization of Ecological Product to the Control of Rocky Desertification in South China Karst. *Sustainability*, 14(5): 3060:1-21.

Huang, W., H. Lai, J. Du, C. Zhou, Z. Liu and Q. Ni. 2022. Effect of polymer water retaining agent on physical properties of silty clay. *Chem. Biol. Technol. Agri*., 9: 47.

Jahan, M. and M.N. Mahallati. 2020. Can superabsorbent polymers improve plants production in arid regions? *Adv. Poly. Technol*., 2020(1): 7124394.

Li, L., H. Zhang, X. Zhou, M. Chen, L. Lu and X. Cheng. 2019. Effects of super absorbent polymer on scouring resistance and water retention performance of soil for growing plants in ecological concrete. *Ecol. Engin*., 138: 237-247.

Liang, Z., X. Cai, H. Hu, Y. Zhang, Y. Chen and Z. Huang. 2021. Synthesis of starch-based super absorbent polymer with high agglomeration and wettability for applying in road dust suppression. *Elsevier*, 183: 982-991.

Liu, H., L. Liu, K. Zhang and R. Geng. 2023. Effect of combining biogeotextile and vegetation cover on the protection of steep slope of highway in northern China: A runoff plot experiment. *Int. J. Sedim. Res*., 38(3): 387-395.

Mechtcherine, V., M. Wyrzykowski, C. Schröfl, D. Snoeck, P. Lura, N. De Belie and S. Igarashi. 2021. Application of super absorbent polymers (SAP) in concrete construction—update of RILEM state-of-the-art report. *Mater. Struct*., 54: 80.

Mohammadpour, R. and G.M.M. Sadeghi. 2020. Effect of liquefied lignin content on synthesis of bio-based polyurethane foam for oil adsorption application. *J. Polym. Environ*., 28: 892-905.

Pramthawee, P., P. Jongpradist and R. Sukkarak. 2017. Integration of creep into a modified hardening soil model for time-dependent analysis of a high rockfill dam. *Comp. Geotech*., 91: 104-116.

Rezashateri, M., S.J. Khajeddin, J. Abedi-Koupai, M.M. Majidi and S.H. Matinkhah. 2016. Growth characteristics ofArtemisia sieberiinfluenced by super absorbent polymers in texturally different soils under water stress condition. *Arch. Agron. Soil Sci*., 63(7): 984-997.

Rizwan, M., S.R. Gilani, A.I. Durani and S. Naseem. 2021. Materials diversity of hydrogel: Synthesis, polymerization process and soil conditioning properties in agricultural field. *Elsevier BV*, 33: 15-40.

Saha, A., S. Sekharan and U. Manna. 2020. Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. *Soil Tillage Res.*, 204:104736.

Song, J., L. Li, Y.H. Niu, R.Y. Ke and X. Zhao. 2022. Preparation of humic acid water-retaining agent-modified polyurethane sponge as a soilless culture material. *J. Appl. Polym. Sci*., 20: 139.

Su, A., S. Niu, Y. Liu, A. He, Q. Zhao, P. Paré and J. Zhang. 2017. Synergistic effects of *Bacillus amyloliquefaciens* (GB03) and water retaining agent on drought tolerance of perennial ryegrass. *Int. J. Mol. Sci*., 18(12): 2651.

Sweijen, T., B. Chareyre, S.M. Hassanizadeh and N.K. Karadimitriou. 2017. Grain-scale modelling of swelling granular materials; application to super absorbent polymers. *Powder Technol*., 318: 411-422.

Tahoun, A.M., M.M.A. El-Enin, A.G. Mancy, M.H. Sheta and A. Shaaban. 2022. Integrative soil application of humic acid and foliar plant growth stimulants improves soil properties and wheat yield and quality in nutrient-poor sandy soil of a semiarid region. *J. Soil Sci. Plant Nutr*., 22(3): 2857-2871.

Tomášková, I., M. Svatoš, J. Macků, H. Vanická, K. Resnerová, J. Čepl, J. Holuša, S.M. Hosseini and A. Dohrenbusch. 2020. Effect of different soil treatments with hydrogel on the performance of drought-sensitive and tolerant tree species in a semi-arid region. *Forests*, 11: 211.

Verma, A.K., S.S. Sindhu, A. Singh, A. Kumar, A. Singh and V.B.S. Chauhan. 2019. Conditioning effects of biodegradable superabsorbent polymer and vermi-products on media properties and growth of gerbera. *Ecol. Engin*., 132: 23-30.

Wei, T., H. Li, N. Yashir, X. Li, H. Jia, X. Ren, J. Yang and L. Hua. 2022. Effects of urease-producing bacteria and eggshell on physiological characteristics and Cd accumulation of pakchoi (*Brassica chinensis* L.) plants. *Environ. Sci. Pollut. Res*., 29(42): 63886-63897.

Xerdiman, D., H. Zhou, S. Li, H. Sun, K. Xin, D. Sun and C. Li. 2022. Effects of water-retaining agent dosages on slope-protection plants and soil nutrients on rocky slopes. *Sustainability,* 14(6): 3615.

Xi, J. and P. Zhang. 2021. Application of super absorbent polymer in the research of water-retaining and slow-release fertilizer. IOP Conference Series. *Earth Environ. Sci*., 651(4): 42066.

Xiaofei, P., B. Xie, X. Zhang, J. Xie and J. Xia. 2024 Matched relationships and mechanisms of water and land resources in Karst Mountainous Areas: A Review. *Land*, 13(6): 813.

Xu, Y., Y. Gao, W. Li, S. Chen, Y. Li and Y. Shi. 2023. Effects of compound water retention agent on soil nutrients and soil microbial diversity of winter wheat in saline-alkali land. *Chem. Biol. Technol. Agri*., 10: 2.

Yan, P., C. Shen, Z. Zou, J. Fu, X. Li, L. Zhang, L. Zhang, W. Han and L. Fan. 2021. Biochar stimulates tea growth by improving nutrients in acidic soil. *Scientia Horticulturae*, 283: 110078.

Yang, M., J. Wu, G.M. Graham, J. Lin and M. Huang. 2021. Hotspots, frontiers, and emerging trends of superabsorbent polymer research: A comprehensive review. *Front. Chem*., 9: 688127.

Zhang, Y., H. Xi and T. Wei. 2023. Improvement of soil quality and pakchoi performance via the application of superabsorbent polymer to cd-contaminated acidic and alkaline soils. *Water, Air, Soil Pollut*., 234: 196.

Zhang, Y., W. Wu, D. Zhang, H. Huang and P. Fang. 2020. Research progress on farmland soil heavy metal pollution and remediation technologies in the Yangtze River Basin. IOP Conference Series: *Earth and Environ. Sci*., 555(1): 12055.

Zhou, C., W. Huang, S. Qiu and Z. Liu. 2021. A quantitative study on the amount of water-retaining agent based on adhesive-modified red bed weathered soil. *Bull. Engin. Geol. and Environ*., 80(4): 3139-3150.

(Received for publication 5 June 2024)