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Soil Moisture and Nutrient Changes of Agroforestry in Karst Plateau Mountain: A Monitoring Example

Ding Luo [1,2], Kangning Xiong [1,*], Chenxu Wu [1], Xing Gu [1] and Zehui Wang [1]

[1] School of Karst Science, Guizhou Normal University/State Engineering Technology Institute for Karst Desertification Control, Guiyang 550001, China
[2] School of Tourism and Resources Environment, Qiannan Normal University for Nationalities, Duyun 558000, China
* Correspondence: xiongkn@gznu.edu.cn

Abstract: To explore soil nutrients and moisture changes in different karst mountain agroforestry, in the plateau mountains of Southern China Karst, we used secondary tree and irrigation forest (C) as a reference for our study and selected four mixed agroforestry species (walnut + maize + potato (HYM), walnut + maize (HTY), poplar + ryegrass (YSH), and maize + ryegrass (YMH)) for comparison. First, soil moisture change characteristics were monitored in situ in the field. Second, for soil samples, soil bulk density, porosity, and permeability were analyzed, soil nutrient (K, Na, Ca, and Mg) characteristics were tested and analyzed. Then, we explored the relationship between agroforestry and soil moisture, soil moisture and soil nutrients, soil moisture and precipitation, and agroforestry and soil nutrients. It is shown (1) during the monitored period, variation trends in soil nutrients in four types of agroforestry was small, but it increased/decreased significantly compared with the secondary forest, which the variation range was more than 5%; (2) the changes of soil water content were significantly affected by precipitation, soil porosity and permeability, the moisture content changes of HYM, HTY, YSH, and YMH agroforestry were significantly correlated with precipitation, soil porosity, and permeability; (3) under the same precipitation conditions, different types had different lags on soil water regulation, with the average HYM 0.8 h, HTY 0.6 h, YSH 0.3 h, and YMH 0.4 h, each type soil responded at 2–3 h after rain, and the soil moisture content returned to the normal level; and (4) the variation of soil moisture content fluctuated seasonally, and the most obvious was HYM and HTY agroforestry, their Cv value between winter and summer exceeded 21%. The results provide basic theoretical support for further exploring the relationship among agroforestry, soil, moisture, and nutrients and enrich the content of the development of agroforestry in karst areas. They are of importance to promote ecological restoration and agroforestry development in karst areas.

Keywords: karst; soil moisture; soil nutrients; agroforestry

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1. Introduction

The karst plateau mountains are an important part of the karst landscape development process, and it records the important information of karst landscape [1]. Guizhou Province is located in the center of South China Karst, with 85% of the province's area covered by karst, and the area of carbonate rocks exposed is 150,000 km^2, accounting for 73.6% of the total land area of Guizhou Province [2]. Karst mountains are characterized by complex topography and landform, high rock exposure rate, shallow and discontinuous soil layer, lack of water and soil on the surface, strong landscape heterogeneity [3,4], and the influencing factors of vegetation restoration are complex [5].

Soil moisture is one of the main influencing factors of hydrologic process, soil erosion process, and plant growth & recovery, it is also the carrier of substance circulation in the soil system [6–9]. There was a very high response relationship between soil moisture and precipitation [10–13]. Karst area of soil moisture and nutrient transfer has significant correlation [14], there are strong interactions between physical, chemical and biological factors of the soil and influence the geochemical processes of the elements [15]. Soil nutrients provide a subsistence base for the growth and development of agroforestry, then soil nutrients are absorbed by agroforestry, soil moisture transport soil nutrients, so that soil nutrients are continuously circulated in the agroforestry space. Exploring the interrelationship between agroforestry, soil moisture and nutrients is the basis for developing of agroforestry in the Karst plateau. Agroforestry has different effects on soil water and nutrient interactions due to differences in their composition type and spatial and temporal structures [16]. As a classic agricultural farming method, agroforestry for excellent economic and ecological benefits and is the preferred form of agricultural farming for ecological restoration and reconstruction in karst areas [17]. Ecological environment restoration and reconstruction can provide theoretical and technical support for land management [18,19], which is widely used in tropical and temperate regions to reduce surface runoff, soil erosion, nutrient, and pollutant losses [20,21]. At present, the research on the relationship between soil water and precipitation, soil nutrients and soil moisture, soil moisture and vegetation, soil nutrients and vegetation [22–24], and other elements in karst areas has grasped a certain basis. However, the relationship between different agroforestry, soil nutrients, and soil moisture in karst area still needs to be further researched. Therefore, the relationship between agroforestry and soil moisture, soil moisture and soil nutrients, soil moisture and precipitation, and agroforestry and soil nutrients are explored in this paper.

2. Materials and Methods

2.1. Study Area

The study area is located in Chongfeng Village, Salaxi Town, Bijie, Guizhou, China (coordinate of center point: 27°15′8.5″ N, 105°5′32″ E, Figure 1), the altitude ranges from 1830 m to 2000 m. Winter is cold and summer is hot, large annual temperature difference, small daily temperature difference, rain-heat period, the annual precipitation is 889.7 mm, 70% of the precipitation is in summer. It has diverse landforms and has the typical mountainous characteristics of the karst plateau. The cultivated land in the area is mainly distributed in the slopes, depressions and valleys, and the land tillage layer is shallow and the fertility is low. The main vegetation is *rhododendron*, *camellia*, *fire thorn*, *roxburghil*, *purple stem zeeland*, *setartail*, *sumac*, *walnut*, *poplar*, *green oka*, *hazelnut*, *masang,* and other shrubs. The main crops are *corn*, *potato*, *soybean*, *red bean*, *buckwheat*, etc.

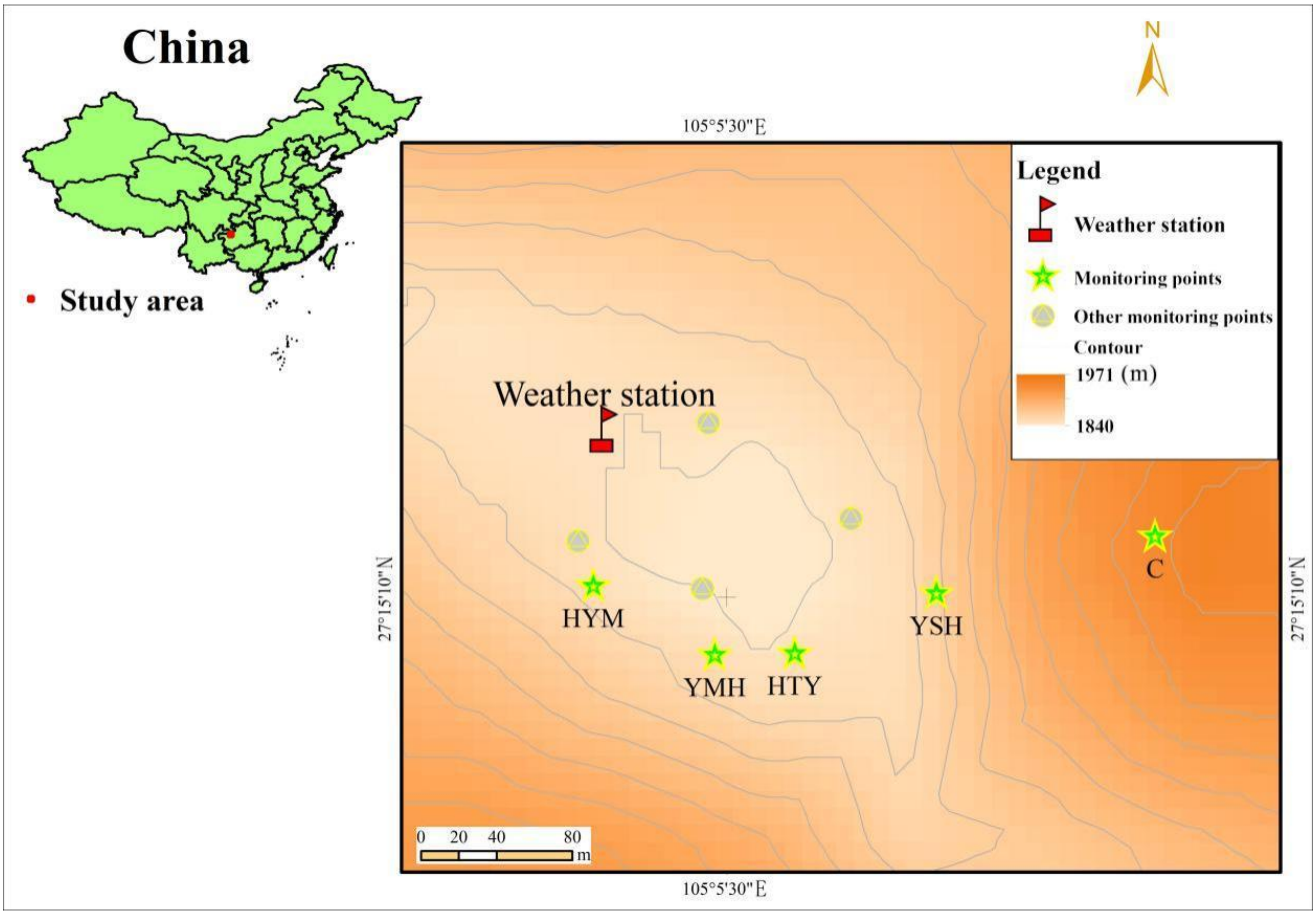


Figure 1. Location of the study area.

2.2. Experimental Design

Four types of typical representative agroforestry in the study area are walnut + maize + potato (HYM), walnut + maize (HTY), poplar + ryegrass (YSH), and maize + ryegrass (YMH) were selected as the monitoring objects, and secondary tree and irrigation forest (C) was used as the study control (Table 1). A total of 5 monitoring points were designed to monitor several main indexes including precipitation, soil moisture content, K, Ca, Mg, Na, soil bulk density, soil porosity, and soil permeability. At each monitoring point, a data recording point/soil sampling point was set up every 15 cm from the surface to the underground. The soil moisture content was monitored in situ in the field, and the instrument recorded the soil moisture data every 30 min; soil nutrients (K, Ca, Mg and Na) were sampled and brought back to the laboratory for air drying and grinding to be tested; soil bulk density, soil porosity, and soil permeability were sampled by ring knife and brought back to the laboratory for testing. We set up a small weather station was installed to record precipitation information every 30 min.

Table 1. Information for each monitoring point.

Monitoring Points	Code	Longitude and Latitude	Type/Agroforestry
Control	C	27°15′14″ N; 105°5′34″ E	Secondary forest
1	YSH	27°15′9″ N; 105°5′31″ E	*Poplar, Ryegrass*
2	YMH	27°15′9″ N; 105°5′30″ E	*Corn, Ryegrass*
3	HTY	27°15′10″ N; 105°5′31″ E	*Walnut, Corn*
4	HYM	27°15′12″ N; 105°5′29″ E	*Walnut, Corn, Potato*

2.3. Sample Analysis

Soil porosity, soil permeability, soil bulk density, and other soil physical properties were measured using procedure [25]; soil nutrients such as Na, Ca, Mg, and K were measured by "Microwave Digestion method for Determination of Total Metal elements in soil and Sediment" HJ 832-2017 [26]; the soil moisture content was monitored and recorded by sensors and data collectors (ECH2O-5TE, EM50).

2.4. Data Analysis

The main statistical analysis methods used in the study are normal distribution test, time series analysis, and Pearson correlation analysis. The experimental data were analyzed and processed with the statistical analysis software Origin2018, Excel2019, and WPS office2022.

3. Results

3.1. Differences in Soil Nutrient Content

Through monitoring data analysis, it was found that K, Ca, Mg and Na in agroforestry soil showed the smallest difference in C, the greatest difference in HTY, and relatively stable in YMH. YSH and HYM were different due to different nutrient types (Figure 2, Table 2). The content of K was the highest in YSH and the lowest in HTY. The content of Ca was the lowest in YSH, the highest in HYM, and the average in C. The content of Mg was the lowest in YSH and the highest in C and HYM. The content of Na in soil was generally low, and the difference was greatest in HTY. During the monitoring period, soil nutrients of the four types of agroforestry significantly increased or decreased compared with secondary forest, and the variation range was greater than 5% (Table 2).

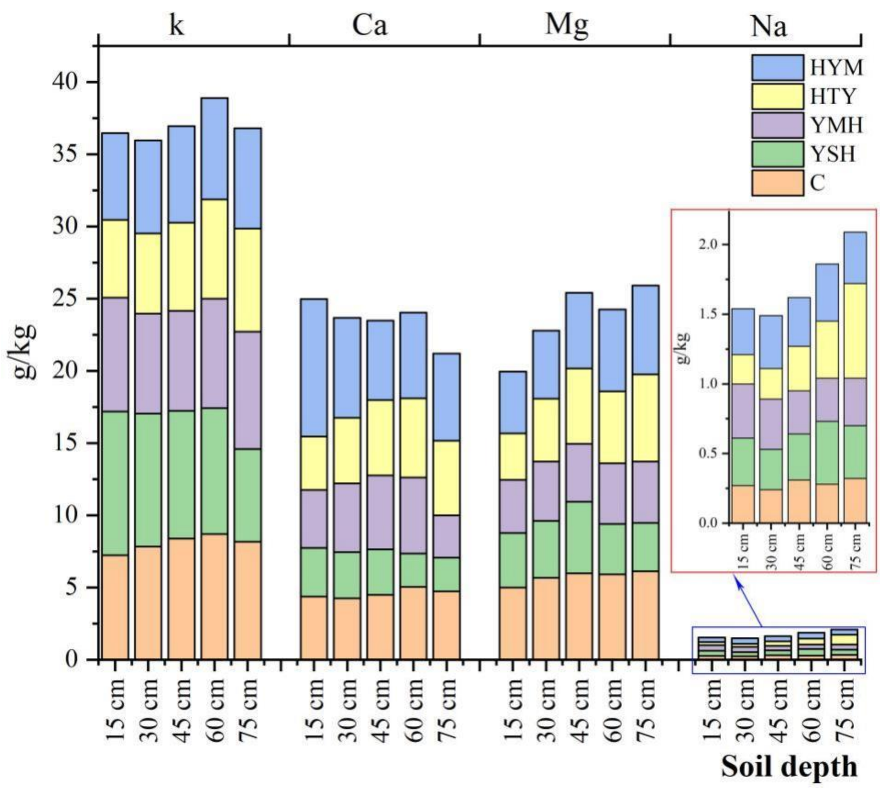


Figure 2. Differences in soil nutrient content.

Table 2. Descriptive analysis of soil nutrients.

Classification		K	Ca	Mg	Na
Total description statistics	Mean value	7.4012	4.6936	4.7316	0.3440
	Standard deviation	1.1638	1.5330	0.9403	0.0913
	Minimum	5.39	2.32	3.21	0.21
	Median	7.15	4.73	4.71	0.33
	Maximum	9.95	9.52	6.15	0.68
C	Mean value	8.06	4.574	5.734	0.284
YSH		8.636	2.876	3.902	0.358
YMH		7.48	4.416	4.046	0.342
HTY		6.218	4.822	4.762	0.368
HYM		6.612	6.78	5.214	0.368

3.2. Soil Permeability and Porosity

It was found that soil porosity in agroforestry was the largest in HYM, and the smallest in HTY and YMH. Soil bulk density showed little difference, which was lower in HTY and slightly higher in YMH (Figure 3). In general, the distribution of soil porosity and bulk density is more concentrated, with soil bulk density averaging at 1.36 g·cm^{-3} and soil porosity averaging at 45.44% for other agroforestry soils, except for HYM, which averages at 60.02%. The permeability of C was the lowest, and that of YSH was similar to that of C, HYM was the highest, and YMH was the second. The soil permeability of agroforestry with the highest permeability reached 170 mL·min^{-1}, and the lowest was less than 10 mL·min^{-1} (Figure 4).

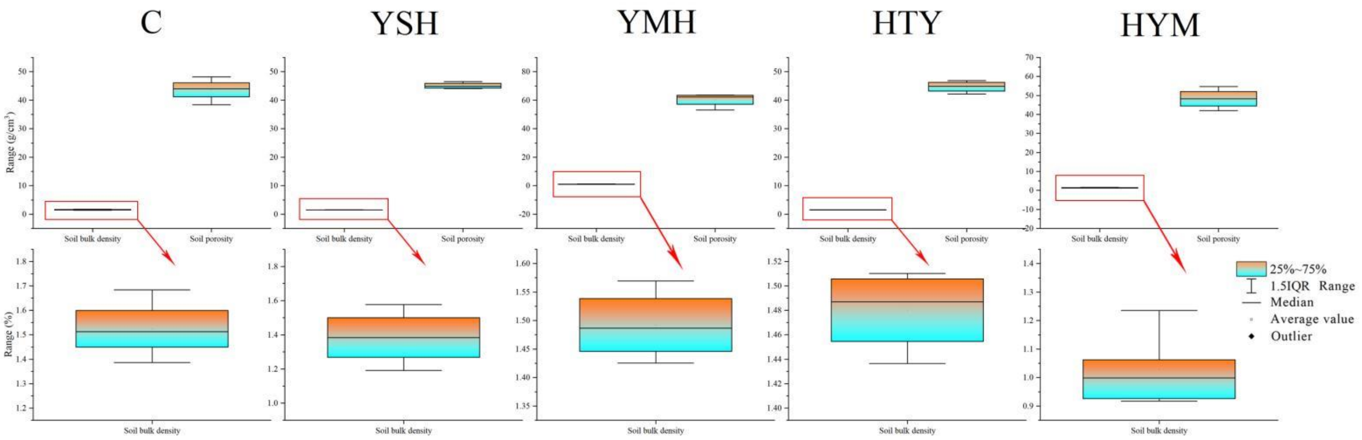


Figure 3. Soil porosity and bulk density of different agroforestry.

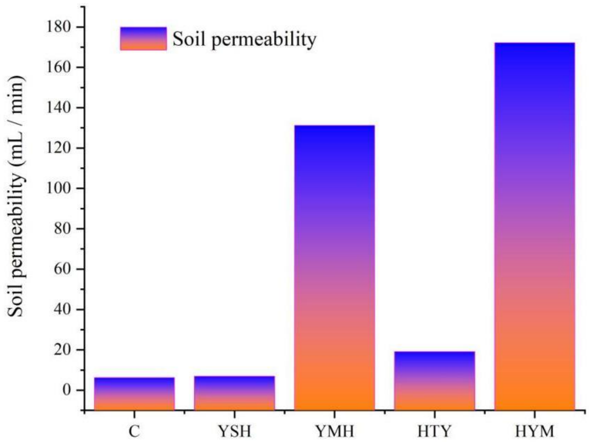
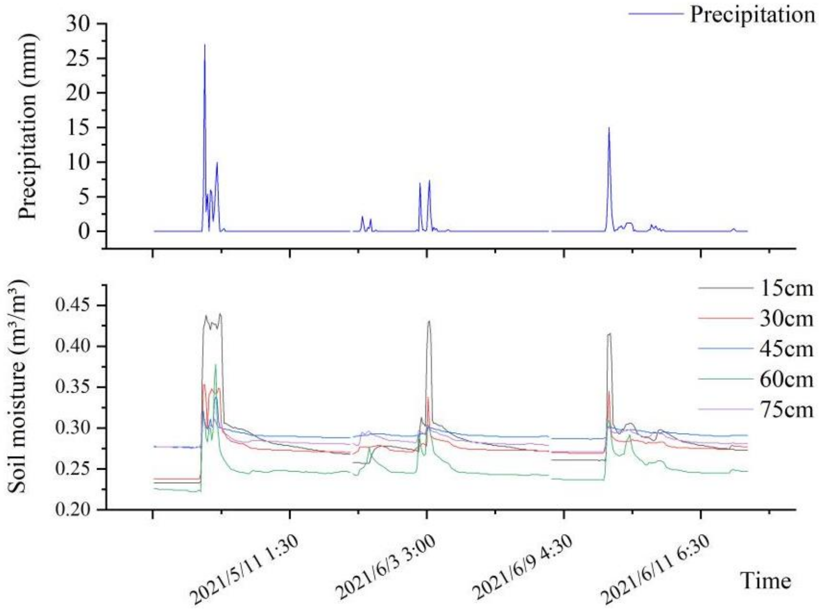


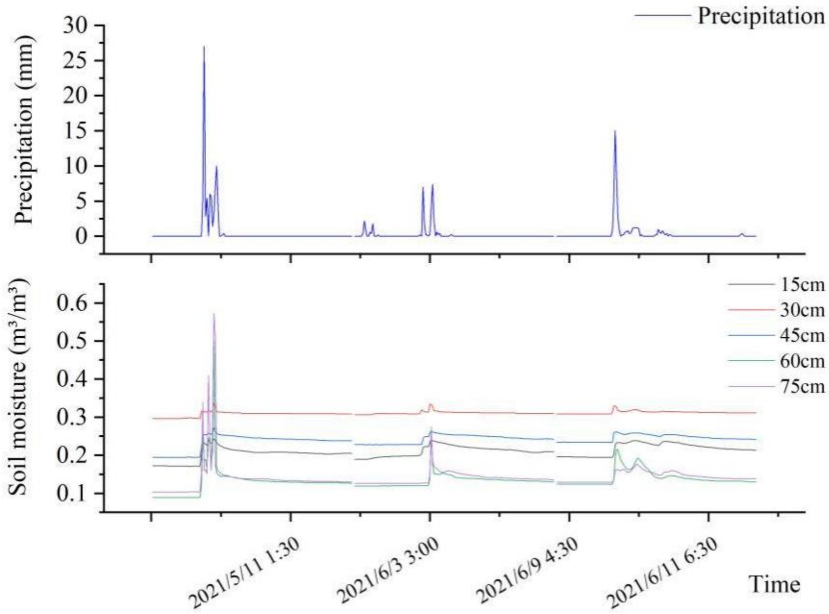
Figure 4. Soil permeability of different agroforestry.

3.3. Soil Moisture Content and Precipitation

There was an obvious response relationship between soil moisture content and precipitation. Soil moisture content increased significantly in the period of high precipitation, and tended to be stable in the period of no precipitation. In YSH and YMH agroforestry, the process of increasing soil moisture content was short and the time of maintaining high moisture content was also short. In C, HTY and HYM agroforestry, the process of increasing soil moisture content lasted longer. In HYM, the soil depth of 45 cm maintained a relatively high moisture content for a long time (Figure 5).

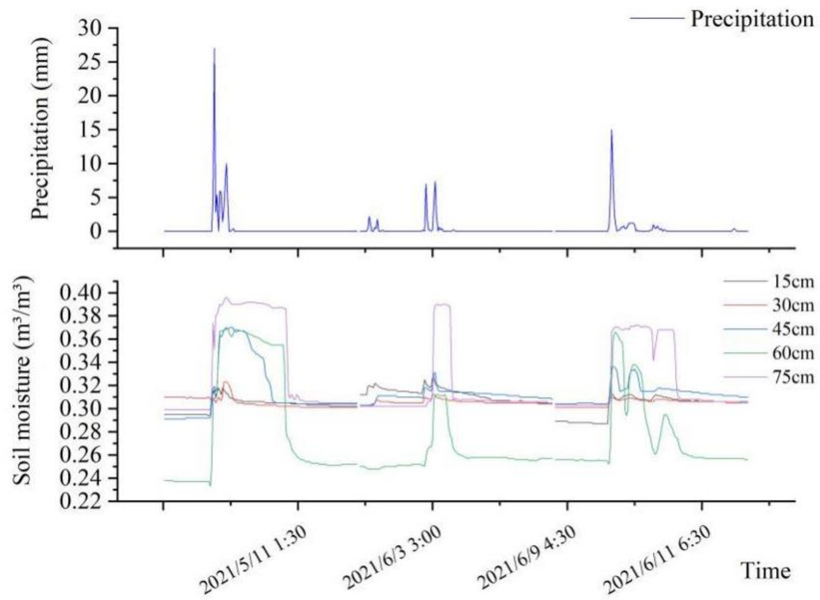


(**a**) **C**

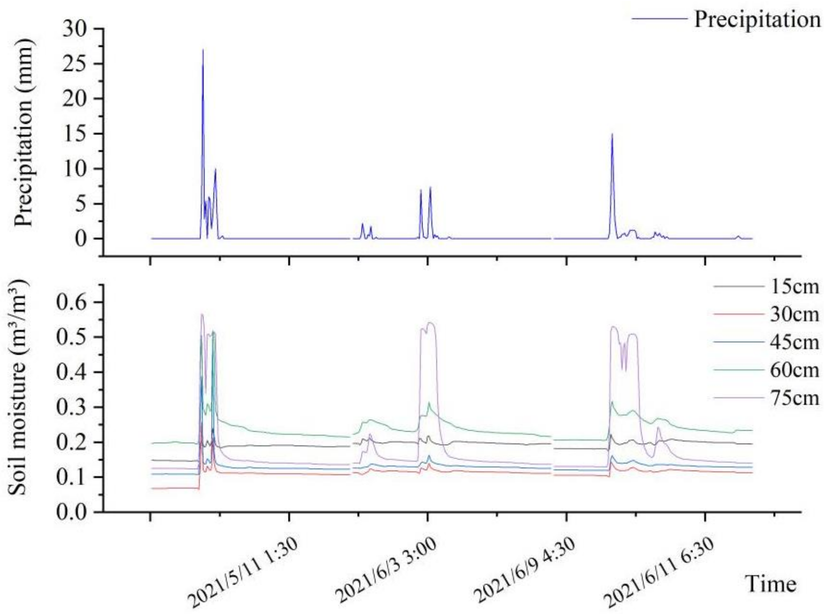


(**b**) **YSH**

Figure 5. *Cont*.

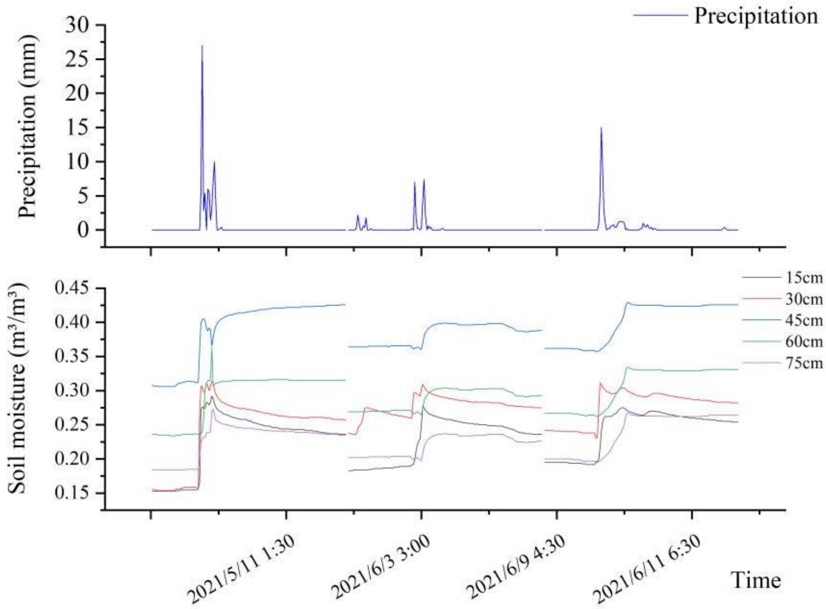


(**c**) **HTY**



(**d**) **YMH**

Figure 5. *Cont*.



(e) HYM

Figure 5. Precipitation and soil moisture of different agroforestry. (C. Secondary forest; YSH. *Poplar, Ryegrass*; YMH. *Corn, Ryegrass*; HTY. *Walnut, Corn*; HYM. *Walnut, Corn, Potato*).

4. Discussion

4.1. Soil Response to Precipitation

Precipitation does not infiltrate immediately after contacting the surface, and is affected by soil permeability, so the response of soil moisture to precipitation only becomes prominent after a lag period [10,27]. Firstly, the lag time varies according to the amount of precipitation, the intensity of rain, the duration of rain, the type of agroforestry, the soil texture, and the surrounding catchment conditions (Figure 5; Figure 6), the response of each agroforestry soil started within 30 min on average after rainfall and ended at 2.5 h after the rain on average. Secondly, the response of soil depth was the most obvious in the range of 0–30 cm, and the response degree gradually decreased with the increase of soil depth, the response degree weakened when the soil depth reached 75 cm. Thirdly, under the same precipitation conditions, different types of agroforestry soils had significant differences in the lag of soil to precipitation regulation, with HYM lagging 0.8 h, HTY lagging 0.6 h, YSH lagging 0.3 h and YMH lagging 0.4 h on average. The response of different types of agroforestry soils ended at 2–3 h after rain. Soil moisture content returned to normal (Figure 5).

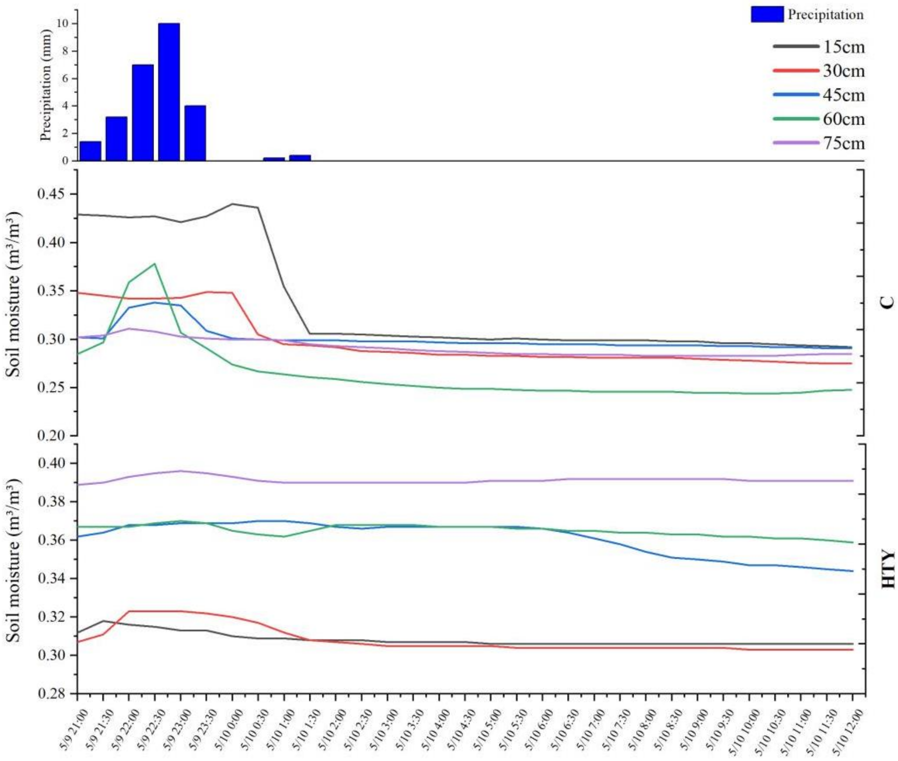


Figure 6. Response of soil moisture to precipitation in single rainfall.

The rainfall of C and HTY on 9 May 2021 was selected as the analysis object.

4.2. Soil Moisture Was Affected by Precipitation, Soil Porosity, and Permeability

Precipitation is the main source of soil moisture acquisition, and the soil moisture content changes in a cliff-like manner before, during and after precipitation (Figure 6). They correlate well with each other (Table 3), and the difference between the rainy season and the dry season is also significant. Rain strength is an important influence factor of soil moisture and nutrient loss on karst slope surface [28]. Soil porosity provides a channel for the infiltration of precipitation into the soil. Soil moisture content in the soil with large porosity increases rapidly after precipitation, and quickly returns to the pre-rainfall level after precipitation. Soil permeability reflects the absorption rate of soil precipitation. In summary, soil porosity and soil permeability have important effects on soil moisture conservation.

Table 3. Analysis of correlation.

Pearson Correlation		**Soil Moisture**	**Soil Porosity**	**Soil Permeability**	**Precipitation**
Soil moisture	Pearson	1	0.36698	−0.12335	0.422
	p	–	0.17845	0.66142	0.01
Soil porosity	Pearson	0.36698	1	0.31054	–
	p	0.17845	–	0.25995	–
Soil permeability	Pearson	−0.12335	0.31054	1	–
	p	0.66142	0.25995	–	–
Precipitation	Pearson	0.422	–	–	1
	p	0.01	–	–	–

4.3. Soil Moisture Content Fluctuated Seasonally

Since there are differences in precipitation between seasons, there are also significant differences in soil water content in agroforestry between seasons. The soil surface moisture content of HYM and HTY was reduced to 0.28 m^3/m^3 in winter and 0.34 m^3/m^3 in summer, respectively. The Cv value of soil moisture content of HYM and HTY was more than 21% between winter and summer. The differences of soil moisture content among the three types of C, YSH and YMH in different seasons are also extremely huge. In YMH, due to the change of surface crops in autumn, soil moisture content decreases significantly (Figure 7).The results are similar to the conclusions of Liu Z.Q. et al. on the hydrological ecological function of typical small watershed in Yunnan plateau [29].

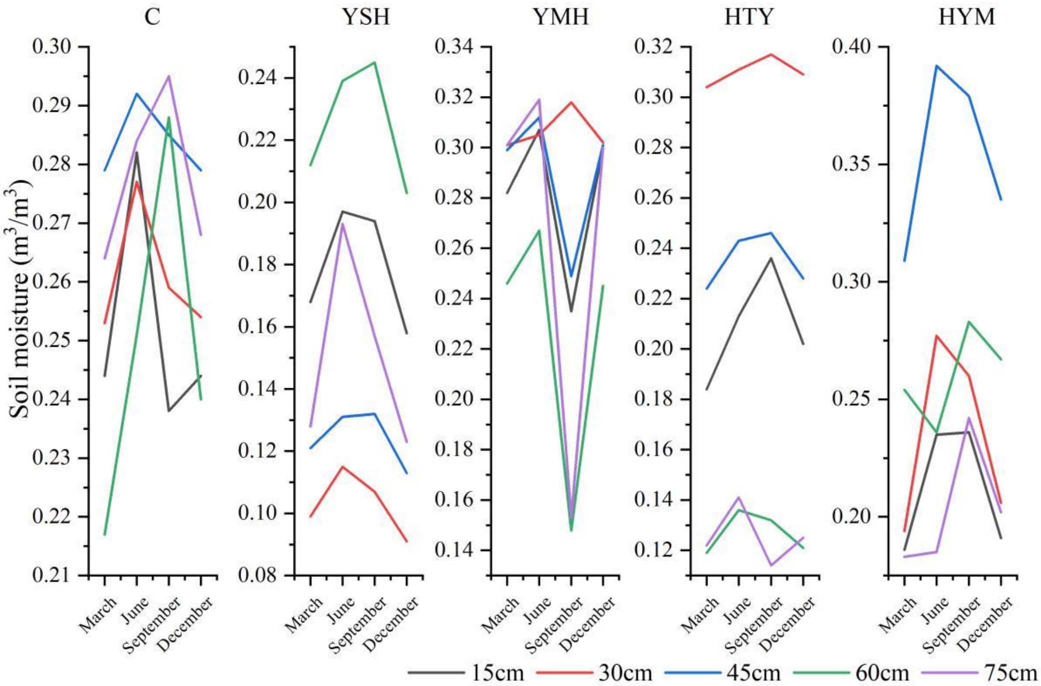


Figure 7. Seasonal variation trend of soil moisture.

4.4. Topographic Environment Is an Important Factor Affecting the Difference of Soil Moisture Content

The topographic environment around the monitoring point has an impact on the factors of precipitation and evaporation. In areas where the surface easily collects runoff, soil water content can be maintained at a high level for a long period of time, areas where evaporation is limited can also experience high soil water content for extended periods of time. However, in areas where runoff is not easily collected on the surface and evaporation conditions are unobvious, soil moisture infiltration is relatively reduced and loss is easy, resulting in an increased possibility of relatively low soil water content [30]. Changes in terrain slope and crop cover are effective measures to affect soil moisture and nutrient changes [31]. The difference of inclination of karst bedrock is an important factor affecting water infiltration [32]. Due to the uneven soil thickness in the monitoring area affected by karst landform, when the monitoring point is too close to the bedrock, the water lost along the bedrock surface during precipitation may affect the soil moisture content, making it abnormally higher than the normal value. Because C is located in near the crest of unfavorable to collect runoff, the site has not experienced water infiltration due to water logging for an extended period of time, the average moisture content has long been at around 0.28 m^3/m^3 (Figure 7), HYM monitoring stations near the bedrock, monitoring results are affected by rapid moisture infiltration and erosion. There is a huge difference in soil water content between the rainy season, dry season, and surface and deep layers (Figure 7).

4.5. The Composition of Agroforestry Is an Important Factor Affecting the Change of Soil Moisture Content

Factors such as soil texture and surrounding soil environment have an impact on the variation of soil moisture content, and the composition difference of agroforestry also has an impact on the variation of soil moisture content. There are differences in the variation of soil moisture characteristics among different vegetation types in karst areas [33,34]. In C, vegetation is the most stable type with the smallest change, and soil moisture content is also the type with the smallest change. Tillage methods have obvious influences on soil properties and maize yield in karst areas [35]. In HYM, the changes of agroforestry vegetation are affected by the tillage process, and crops change frequently, leading to the largest changes in soil moisture content (Table 1, Figure 7). Canopy gaps between secondary beech forests affect the water retention capacity of soil and vegetation [36]. There were also differences in soil moisture content between the growing season and fallow period of several monitored agroforestry (Figure 7).

5. Conclusions

To study the connection law between agroforestry and soil moisture, soil moisture, and soil nutrient from the perspective of karst landform environment. The development of agroforestry in karst areas should pay attention to the relationship between agriculture and environment, especially the influence of soil and precipitation elements on agroforestry in karst areas. The main findings of this study are as follows: (1) during the monitored period, the variation trend of soil nutrients in the four types of agroforestry was small, but it increased or decreased significantly compared with the secondary forest, and the variation range was more than 5%; (2) the changes of soil water content were significantly affected by precipitation, soil porosity, and permeability, the moisture content changes of HYM, HTY, YSH, and YMH agroforestry were significantly correlated with precipitation, soil porosity, and permeability; (3) under the same precipitation conditions, different types of agroforestry on soil water regulation had different lags, with the average HYM 0.8 h, HTY 0.6 h, YSH 0.3 h, and YMH 0.4 h, each type of agroforestry soil responded at 2–3 h after rain, and the soil moisture content returned to the normal level; (4) the variation of soil moisture content fluctuated seasonally, and the most obvious was HYM and HTY agroforestry, the Cv value between winter, and summer exceeds 21%. Whether the response time of soil water to precipitation will lag more than a few months when the soil depth is more than 60 cm in some areas? Although there are some verification in the chart, the regularity needs to be further studied; then, we need to further verify the extent to which lithology affects soil under agroforestry conditions; finally, the effects of tillage methods and crop planting cycle on soil moisture and nutrients in karst agroforestry also need to be further verified and analyzed.

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