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Preliminary Study on the Effect of Different Ecological Cultivation Modes on the Water Stability of Soil Aggregates in Rubber Based Agroforestry Systems

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Abstract

Rubber trees (*Hevea brasiliensis* Müll. Arg.) have been commercially cultivated for a century and a half in Asia, particularly in China, and they constitute a common element of plantation ecosystems in tropical regions. Soil health is fundamental to the sustainable development of rubber plantations. The objective of the study is to explore the influence of different complex ecological cultivation modes on the stability of soil aggregates in rubber based agroforestry systems. In this study, the ecological cultivation mode of rubber—*Alpinia oxyphylla* plantation, the ecological cultivation mode of rubber—*Phrynium hainanense* plantations, the ecological cultivation mode of rubber—*Homalium ceylanicum* plantations and monoculture rubber plantations were selected, and the particle size distribution of soil aggregates and their water stability characteristics were analyzed. The soil depth of 0 - 20 cm and 20 - 40 cm was collected for four cultivation modes. Soil was divided into 6 particle levels > 20 cm. soil was divided into 6 particle levels > 5 mm, 2 - 5 mm, 1 - 2 mm, 0.5 - 1 mm, 0.25 - 0.5 mm, and 0.053 - 0.25 mm according to the wet sieve method. The particle size proportion and water stability of soil aggregates were determined by the wet sieve method. The particle size proportion and water stability of soil aggregates under different ecological cultivation modes were analyzed. The results showed that under different ecological cultivation modes in the shallow soil layer (0 - 20 cm), the rubber—*Alpinia oxyphylla* plantation and the rubber—*Phrynium hainanense* plantation

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promoted the development of dominant soil aggregates towards larger size classes, whereas the situation is the opposite for rubber—*Homalium ceylanicum* plantation. In soil layer (20 - 40 cm), the ecological cultivation mode of rubber—*Phrynium hainanense* plantation developed the dominant radial level of soil aggregates to the diameter level of large aggregates. Rubber—*Alpinia oxyphylla* plantation and rubber—*Homalium ceylanicum* plantation, three indicators, including the water-stable aggregate content $R_{0.25}$ (>0.25 mm water-stable aggregates), mean weight diameter (MWD), and geometric mean diameter (GMD), were all lower than those in the rubber monoculture mode. However, in the rubber—*Phrynium hainanense* plantation, the water-stable aggregate content $R_{0.25}$, mean weight diameter, and geometric mean diameter were higher than in the rubber monoculture mode, although these differences did not reach statistical significance.

Keywords

Ecological Complex Cultivation, Rubber Plantation, Soil Aggregates, Soil Aggregate Water Stability, Rubber Based Agroforestry Systems

1. Introduction

Soil aggregates, as the basic building blocks of soil structure, are not only important carriers of soil fertility, but also key indicators of soil stability and soil quality [1]. It is not only an important carrier of soil fertility but also a key indicator of the stability of soil structure and soil quality [2]. It is also a key indicator of the stability of soil structure and soil quality. Soil aggregates of different grain sizes play different roles in soil nutrient supply, transformation, and retention [3]. Soil aggregate stability is a key indicator of soil structure stability and soil quality. Soil aggregate stability is an important indicator of soil structure, divided into water stability, mechanical stability, and biological stability, which can reflect the physical process of soil erosion by rain, extrusion, and the formation of sloughing [4] [5]. It can reflect the physical process of soil erosion by rain, compression, and formation of sloughing. Therefore, the water stability of soil aggregates and soil aggregate water stability have attracted much attention in the study of land use change [5]. The water stability of >0.25 mm The proportion of >0.25 mm water-stable aggregates ($R_{0.25}$), the mean weight diameter (MWD), and the geometric mean diameter (GMD) are often used as indicators of the water stability of soil aggregates [6]. The higher the content of >0.25 mm soil aggregates, the higher the values of MWD and GMD, and the better the distribution and stability of soil aggregates [7].

Natural rubber is an important industrial raw material for national security and social livelihoods [8]. In 2021, the total amount of natural rubber produced in China will be 85.13 million tonnes, while the total amount of imports will be 5.3828 million tonnes [9]. In 2021, the total amount of natural rubber produced in China will be 85.13 million tonnes, while the total amount of imports will be 538.28 million tonnes. In terms of supply and demand, the imbalance between supply and demand of natural rubber in China still needs to be changed urgently. Therefore, it should be possible to solve the contradiction between supply and demand by expanding the planting area of rubber trees in China to increase the production of natural rubber. In 2022, the planting area of natural rubber in China will be 1.12 million hectares, which is still a long way from the target of 1.2 million hectares of protected area for the production of rubber trees in China [10]. The production system formed by single rubber tree planting has a single structure, and the slightest carelessness in the production and conservation measures will easily cause soil quality degradation and even lead to problems such as the instability of the system structure [11] [12]. Cultivation of rubber trees in combination with other crops can effectively reduce the kinetic energy of raindrops and the erosive power of rainfall on the soil in rubber plantations [13]. The rubber tree and tea tree cultivation model can make full use of space, improve soil fertility, and generate higher economic returns [14]. The rubber tree composite tea tree cultivation model can make full use of space, improve soil fertility, and generate higher economic returns. Therefore, changing the single rubber tree plantation structure and adopting the rubber tree composite business model is expected to overcome the above problems and promote the sustainable development of the rubber agroforestry ecosystem. The land use of rubber monocultures transformed into agroforestry composite ecosystem mode is changed, and the original understorey soil structure and soil quality may change accordingly. Some studies have shown that the creation of eucalyptus mixed forests can increase the quality of apoplastic material, improve the stability of soil aggregates, and promote the formation of large aggregates [15]. The study shows that the creation of eucalyptus mixed forest can increase the quality of apoptosis improve the stability of soil aggregates and promote the formation of large aggregates. The adoption of suitable composite patterns in prickly pear orchards is conducive to increasing the content of soil macro aggregates and their contribution to soil nutrients [16]. The soil agglomerates of different forest types will be increased. Among the soil aggregates in different forest types, the stability of soil aggregates in mixed fir forests was significantly higher than that in pure fir forests [17]. In conclusion, although many scholars have conducted research on the effects of agroforestry systems on soil aggregates, there is still a significant lack of research on the water stability of soil aggregates in rubber based agroforestry systems. Therefore, in this study, we selected the ecological cultivation mode of rubber—*Alpinia oxyphylla* plantations, the ecological cultivation mode of rubber plantation compound *Phrynium hainanense* plantations, and the ecological cultivation mode of rubber—*Homalium ceylanicum* as research objects, rubber monoculture mode as a control, and rubber pure forest as a control, to explore the effects of composite ecological modes on the stability of soil agglomerates in rubber plantations, intending to provide an in-depth understanding of the effects of rubber agroforestry composite systems on soils and the rubber composite to provide scientific basis for the in-depth understanding of the effect of rubber agroforestry complex system on soil and the sustainable use of soil under the rubber ecological complex cultivation.

2. Materials and Methods

2.1. General Information about the Study Site

The experimental sites were selected in Qingsong Town and Qifang Town of Baisha Lizu Autonomous County, Hainan Province, and Donghe Town of Dongfang City, Hainan Province. Qingsong Town has a tropical monsoon climate with abundant light and suitable rainfall. The planting mode selected for the experiment is the ecological cultivation mode of rubber—*Alpinia oxyphylla* plantation and the planting mode of the selected compound ecology for the experiment is the ecological cultivation mode of the rubber—*Phrynium hainanense* plantation at Qifang Town. Donghe Town, Dongfang City, Hainan Province, is mostly surrounded by mountains in a mountainous basin, and the composite ecological planting model selected for the experiment is the ecological cultivation mode of rubber—*Homalium ceylanicum*.

2.2. Experimental Design and Experimental Materials

The rubber plantations were intercropped using either Michelia macclure or Mytilaria laosensis, and there was also a nonintercropped control.

Rubber plantations of different ecological composites were selected as test forests and pure rubber plantations in the corresponding areas as controls. Three sample points were randomly selected in the rainy season between the rubber and the composite crop rows at a distance of 4 m. Soil was collected from the 0 - 20 cm and 20 - 40 cm soil horizons. Soil was collected from the 0 - 20 cm and 20 - 40 cm soil horizons at a distance of 4 m. Soil was removed from the soil layer, mixed with debris, placed in clean plastic storage bags, and brought back to the laboratory. The collected soil will be used for experimental measurements and to obtain data.

2.3. Measurement and Methods

Soil water-stable aggregates were determined by the wet sieve method [18]. A soil sample of 100 g was weighed. The soil sample was weighed at 100 g. The soil sample was placed in a 1 L measuring cylinder, slowly filled with deionized water along the wall of the tube until it did not exceed the soil sample, and left to stand for 10 min to expel the air in the soil and prevent the occluded air from destroying the soil aggregates, and then injected with deionized water to the 1-liter mark, and left to stand for a further 10 min. The soil sample, which had been left to stand for 10 min, was then transferred to a set of sieves (5, 2, 1, 0.5, 0.25. 0.053 mm, 0.053 mm) 5 mm sieve (sieve frame in advance, immersed in a bucket of water, the water surface should be 5 - 6 cm above the upper sieve surface). The set of sieves in the water slowly lifted and then more quickly down to raise the set of sieves, repeated 10 times, can be stopped. The soil particles left on the sieve at all levels will be washed into the evaporation dish with the lower water bottle, left to stand, and poured out in the upper part of the clear night. Then transfer the soil sample to the aluminum box, bake in the oven until constant weight, weigh, and calculate the mass of agglomerates.

2.4. Data Processing

2.4.1. Calculation of Soil Aggregate Stability Indicators

The water-stable aggregate content ($R_{>0.25}$), mean mass diameter (MWD), and geometric mean diameter (GMD) of soil aggregates > 0.25 mm were calculated according to the method in Lu Mei, respectively [19]. Method

$$R_{0.25} = \frac{m_{>0.25}}{m_T} \times 100\% ; \tag{1}$$

where: m > 0.25 mm is the mass of agglomerates larger than 0.25 mm, g; m_T is the total mass of agglomerates at all levels, g; and

$$MWD = \sum_{i=1}^{n} \bar{X}_i \times W_i ; \tag{2}$$

where: $\bar{X}_i$ is the average diameter of the agglomerates at each level, mm; W_i is the mass percentage of the agglomerates at each level (%).

$$GMD = \exp\left[\frac{\sum_{i=1}^{n} W_i \ln \bar{X}_i}{\sum_{i=1}^{n} W_i}\right]; \tag{3}$$

where: $\bar{X}_i$ is the average diameter of water-stable agglomerates of each grain level (mm); W_i is the mass percentage of water-stable agglomerates of each grain level (%).

2.4.2. Data Processing Methods

The experimental data were statistically processed using Microsoft Excel 2019 software. Analysis of variance (ANOVA) was performed using IBM SPSS STATISTICS 27.

3. Results

3.1. Composition of Shallow (0 - 20 cm) Soil Stability Aggregates under Different Ecological Cultivation Patterns

As can be seen from the data in **Table 1**, in the shallow soil, only the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree had significant differences in soil aggregate content, *i.e.*, the soil aggregate content of >5 mm in the composite ecological cultivation mode was significantly smaller than that of the monoculture, and the remaining There was no significant difference in soil aggregate content between the ecological cultivation mode and the control. In the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree, the dominant size class was 2 - 5 mm, followed by 1 - 2 mm, and the dominant size class of monoculture

Table 1. Distribution of particle size of shallow (0 - 20 cm) soil water-stable aggregates under different ecological cultivation modes.

Cultivation mode	Grain size					
	>5 mm	2 to 5 mm	1 to 2 mm	0.5 to 1 mm	0.25 to 0.5 mm	0.053 to 0.25 mm
YZ	5.05 ± 2.54[b]	21.97 ± 12.65[a]	21.32 ± 3.32[a]	18.83 ± 6.02[a]	16.58 ± 5.75[a]	16.25 ± 5.16[a]
CK1	18.57 ± 9.22[a]	23.85 ± 5.55[a]	15.41 ± 1.30[a]	19.76 ± 4.23[a]	12.32 ± 4.58[a]	10.10 ± 3.10[a]
ZY	14.20 ± 12.24[a]	29.18 ± 4.03[a]	24.38 ± 6.86[a]	16.22 ± 3.92[a]	8.30 ± 3.20[a]	7.72 ± 2.37[a]
CK2	6.18 ± 3.78[a]	21.62 ± 9.25[a]	19.92 ± 6.53[a]	24.13 ± 10.70[a]	13.61 ± 4.18[a]	14.55 ± 5.30[a]
HH	5.84 ± 3.45[a]	2.52 ± 1.13[a]	5.27 ± 0.90[a]	13.77 ± 2.75[a]	19.49 ± 2.96[a]	53.10 ± 5.74[a]
CK3	7.55 ± 5.35[a]	16.26 ± 17.52[a]	7.99 ± 3.16[a]	10.75 ± 3.77[a]	15.58 ± 5.00[a]	41.87 ± 13.30[a]

Note: The data in the table are mean ± standard error. YZ in the table are the ecological cultivation mode of rubber—*Alpinia oxyphylla*, ZY is the ecological cultivation mode of rubber—*Phrynium hainanense*, HH is the ecological cultivation mode of rubber—*Homalium ceylanicum*, and CK1 - 3 corresponds to its native rubber pure forest in turn. Forest compound *Phrynium hainanense*, HH is the ecological cultivation mode of rubber—*Homalium ceylanicum*, and CK1, CK2, CK3 corresponds to its rubber monoculture, respectively. Different lowercase letters in the same column represent the different cultivation modes under different cultivation modes. Lowercase letters represent significant differences ($p < 0.05$) in soil aggregate content between different cultivation modes.

was 1 - 5 mm, followed by 0.5 - 1 mm. In the ecological cultivation mode of rubber plantation compound *Phrynium hainanense*, the dominant diameter class is 2 - 5 mm, 0.5 - 1 mm, and the single-crop dominant diameter class is 2 - 5 mm, 0.5 - 1 mm; in the ecological cultivation mode of rubber - *Homalium ceylanicum*, the dominant diameter level is 0.25 - 0.5 mm, 0.053 - 0.25 mm is second, and the dominant diameter level of a single crop is 2 - 5 mm, 0.053 - 0.25 mm is second. In comparison, the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree and the ecological cultivation mode of rubber plantation compound *Phrynium hainanense* can lead to the development of soil aggregate dominance to large aggregate size classes, while the opposite is true for the ecological cultivation mode of rubber—*Homalium ceylanicum*.

3.2. Composition of Shallow (20 - 40 cm) Soil Stability Aggregates under Different Ecological Cultivation Patterns

As can be seen from the data in Table 2, in the deep soil, only the ecological cultivation mode of rubber plantation compound *Phrynium hainanense* had a significant difference in soil aggregate content, *i.e.*, the soil aggregate content of >5 mm in the compound ecological cultivation mode was significantly greater than that of the single crop, and the rest of the compound ecological In the ecological cultivation mode, the soil aggregate content of >5 mm was significantly higher than that of the monoculture, while the rest of the ecological cultivation modes did not differ significantly from the control. In the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree, the dominant size class was 1 - 2 mm, followed by 0.5 - 1 mm, while the dominant size class of monoculture was 2 - 5 mm, followed by 0.5 - 1 mm. In the ecological cultivation mode of rubber

Table 2. Distribution of particle size of soil water-stable aggregates in deep layer (20 - 40 cm) under different ecological cultivation modes.

Cultivation mode	Grain size					
	>5 mm	2 to 5 mm	1 to 2 mm	0.5 to 1 mm	0.25 to 0.5 mm	0.053 to 0.25 mm
YZ	1.66 ± 0.83^a	12.93 ± 3.81^a	22.92 ± 4.25^a	21.98 ± 1.42^a	21.64 ± 2.46^a	18.88 ± 3.85^a
CK1	12.75 ± 6.10^a	20.48 ± 4.48^a	18.67 ± 3.94^a	22.16 ± 6.53^a	12.59 ± 3.23^a	13.35 ± 2.36^a
ZY	18.37 ± 13.04^a	19.32 ± 9.30^a	20.72 ± 4.22^a	20.32 ± 14.46^a	12.76 ± 8.61^a	8.51 ± 3.03^a
CK2	2.12 ± 1.94^b	16.97 ± 8.48^a	25.39 ± 6.21^a	20.43 ± 5.76^a	18.06 ± 5.17^a	17.03 ± 4.62^a
HH	2.03 ± 0.43^a	2.17 ± 0.10^a	5.27 ± 1.09^a	14.39 ± 5.24^a	20.00 ± 3.40^a	56.14 ± 8.81^a
CK3	9.72 ± 10.69^a	8.58 ± 5.19^a	5.90 ± 0.65^a	12.79 ± 2.05^a	16.09 ± 5.33^a	46.93 ± 20.22^a

Note: The data in the table are mean ± standard error; YZ in the table are the ecological cultivation mode of rubber—*Alpinia oxyphylla*, ZY is the ecological cultivation mode of rubber—*Phrynium hainanense*, HH is the ecological cultivation mode of rubber—*Homalium ceylanicum*, and CK1, CK2, CK3 corresponds to its rubber monoculture, respectively. Different lowercase letters in the same column represent the different cultivation modes under different cultivation modes. Lowercase letters represent significant differences ($p < 0.05$) in soil aggregate content between different cultivation modes.

plantation compound *Phrynium hainanense*, the dominant diameter class was 1 - 2 mm, 0.5 - 1 mm, and the single-crop dominant diameter class was 1 - 2 mm, 0.5 - 1 mm; in the ecological cultivation mode of rubber—*Homalium ceylanicum*, the dominant diameter level is 0.25 - 0.5 mm, 0.053 - 0.25 mm is the next best, and the single-crop dominant diameter level is 0.25 - 0.5 mm, 0.053 - 0.25 mm is the next best. The comparison shows that all three compound ecological cultivation modes of rubber lead to the development of soil aggregates dominant size class to small aggregates size class.

3.3. Effect of Stability Characteristics of Shallow (0 - 20 cm) Soil Aggregates under Different Ecological Cultivation Modes

Soil aggregate water stability can be described by $R_{0.25}$, MWD, and GMD, and larger values of these three indicators indicate a more stable soil structure [18]. As can be seen from the data in **Table 3**, in shallow soil, under the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree, the composite ecological cultivation mode $R_{0.25}$ (83.75%) was lower than the monoculture $R_{0.25}$ (89.90%), the composite ecological cultivation Under the ecological cultivation mode, $R_{0.25}$ (83.75%) was lower than $R_{0.25}$ (89.90%) in monoculture, MWD (1.57 mm) was lower than MWD (2.20 mm) in monoculture, and GMD (0.97 mm) was lower than GMD (1.37 mm) in monoculture. Under the ecological cultivation mode of rubber—*Homalium ceylanicum*, the composite ecological cultivation mode $R_{0.25}$ (46.90%) was lower than the monoculture $R_{0.25}$ (58.13%), the composite ecological cultivation mode MWD (0.72 mm) was lower than MWD (1.27 mm) in monoculture, and GMD (0.34 mm) was lower than GMD (1.02 mm) in the ecological cultivation mode. Under the ecological cultivation mode of rubber plantation compound *Phrynium hainanense*, the composite ecological cultivation mode $R_{0.25}$ (92.28%) was higher than the monoculture $R_{0.25}$ (85.45%), the composite

Table 3. Characteristics of shallow (0 - 20 cm) soil aggregates under different ecological cultivation modes.

Cultivation mode	$R_{0.25}$/%	MWD/mm	GMD/mm
YZ	83.75 ± 5.16^{a}	1.57 ± 0.52^{a}	0.97 ± 0.34^{a}
CK1	89.90 ± 3.10^{a}	2.20 ± 0.45^{a}	1.37 ± 0.37^{a}
ZY	92.28 ± 2.37^{a}	2.26 ± 0.42^{a}	1.54 ± 0.31^{a}
CK2	85.45 ± 5.30^{a}	1.62 ± 0.48^{a}	1.02 ± 0.37^{a}
HH	46.90 ± 5.74^{a}	0.72 ± 0.13^{a}	0.34 ± 0.04^{a}
CK3	58.13 ± 13.30^{a}	1.27 ± 0.76^{a}	0.61 ± 0.36^{a}

Note: The data in the table are mean ± standard error; the letters YZ in the table are the ecological cultivation mode of rubber—*Alpinia oxyphylla*, ZY is the ecological cultivation mode of rubber—*Phrynium hainanense*, HH is the ecological cultivation mode of rubber—*Homalium ceylanicum*, and CK1, CK2, CK3 corresponds to its rubber monoculture, respectively. Different lowercase letters in the same column represent the different cultivation modes under different cultivation modes. Lowercase letters represent significant differences ($p < 0.05$) in soil aggregate content between different cultivation modes.

ecological cultivation mode MWD (2.26 mm) was higher than the monoculture MWD (1.62 mm), and GMD of the ecological cultivation mode (1.54 mm) was higher than that of the monoculture (1.02 mm). Under the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree and the ecological cultivation mode of rubber—*Homalium ceylanicum*, all three indicators were lower in the composite ecological cultivation than in the monoculture; the opposite was true for the ecological cultivation mode of rubber plantation compound *Phrynium hainanense*, but the differences between treatments and control were not significant.

3.4. Effect of Stability Characteristics of Deep (20 - 40 cm) Soil Aggregates under Different Ecological Cultivation Modes

As can be seen from the data in Table 4, in deep soil, under the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree, the composite ecological cultivation mode $R_{0.25}$ (81.13%) was lower than the monoculture $R_{0.25}$ (86.65%), the composite ecological cultivation MWD (1.15 mm) was lower than MWD (1.87 mm) of monoculture, and GMD (0.71 mm) was lower than GMD (1.12 mm) of composite ecological cultivation mode, but the differences between the treatments and the control did not reach the significant level. Under the ecological cultivation mode of rubber plantation compound *Phrynium hainanense*, the composite ecological cultivation mode $R_{0.25}$ (91.49%) was higher than the monoculture $R_{0.25}$ (82.97%), the composite ecological cultivation mode MWD (2.12 mm) was higher than the monoculture MWD (MWD (2.12 mm) was higher than MWD of monoculture (1.33 mm), GMD of the ecological cultivation mode (1.43 mm) was higher than that of monoculture (0.84 mm), and the difference with GMD of the control reached a significant level. Under the ecological cultivation mode of rubber—*Homalium ceylanicum*, $R_{0.25}$ (43.86%) of the composite

Table 4. Characteristics of deep soil (20 - 40 cm) aggregates.

Cropping patterns	$R_{0.25}$/%	MWD/mm	GMD/mm
YZ	81.13 ± 3.85^a	1.15 ± 0.17^a	0.71 ± 0.11^a
CK1	86.65 ± 2.36^a	1.87 ± 0.38^a	1.12 ± 0.25^a
ZY	91.49 ± 3.03^a	2.12 ± 0.88^a	1.43 ± 0.61^a
CK2	82.97 ± 4.61^a	1.33 ± 0.37^a	0.84 ± 0.23^b
HH	43.86 ± 8.80^a	0.52 ± 0.03^a	0.30 ± 0.03^a
CK3	53.07 ± 20.22^a	1.10 ± 0.68^a	0.51 ± 0.30^a

Note: The data in the table are mean ± standard error; the letters YZ in the table are the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree, ZY is the ecological cultivation mode of rubber plantation compound *Phrynium hainanense*, HH is the ecological cultivation mode of rubber—*Homalium ceylanicum*, and CK1 - 3 corresponds to its rubber monoculture in turn; different lowercase letters in the same column represent the different cultivation modes under different cultivation modes. Lowercase letters represent significant differences ($p < 0.05$) in soil aggregate content between different cultivation modes.

ecological cultivation mode was lower than that of the monoculture $R_{0.25}$ (53.07%), MWD (0.52 mm) was higher than that of the control GMD. MWD (0.52 mm) was lower than MWD (1.10 mm) of monoculture and GMD (0.30 mm) was lower than GMD (0.51 mm) of monoculture, but the differences between treatments and control did not reach a significant level.

4. Discussion

Soil aggregates can be categorized into macroaggregates (>0.25 mm) and microaggregates (<0.25 mm) according to particle size [20]. Changes in land use will cause changes in the distribution of soil aggregates, as well as changes in the stability of soil aggregates. According to the data of this study, it can be obtained that the ecological cultivation mode of rubber—*Alpinia oxyphylla* tree and the ecological cultivation mode of rubber—*Homalium ceylanicum* both increased the proportion of micro aggregates (<0.25 mm) in the soil and reduced the $R_{0.25}$, MWD, and GMD indicators, the ecological cultivation mode of rubber plantation compound *Phrynium hainanense* increased the proportion of microaggregates (<0.25 mm) in the soil, and the indicators of $R_{0.25}$, MWD, and GMD became smaller, which is consistent with the results of the study of corn-soybean intercropping [21], both of which have the effect of increasing the proportion of soil microaggregates (<0.25 mm) in the soil. This research result is consistent with that of corn-soybean intercropping [22], which has the effect of improving soil aggregate stability. The possible reasons for the improved soil aggregate stability of the composite ecological cultivation model are that the composite ecological cultivation can improve the root dry mass of the crop root system, total root length, root secretion of total sugar content, root secretion of total organic acid content, and so on, which in turn improves the stability of the soil aggregates [22], or it may be since complex cultivation of the crop root system through the role of entanglement and solidification so that the soil is more likely to form a larger particle size of the aggregate [20]; may also be caused by changes in the biodiversity of soil microorganisms in the rhizosphere due to complex cultivation [23]. In addition, it has been shown that the creation of mixed eucalyptus forests can increase the quality of apoplastic material and thus improve the stability of soil aggregates [15].

The ecological cultivation mode of rubber—*Alpinia oxyphylla* tree and the ecological cultivation mode of rubber—*Homalium ceylanicum* both increased the percentage of micro aggregates (<0.25 mm) in the soil, and the results of smaller $R_{0.25}$, MWD, and GMD were similar to those of sweet potato interplanted between rows in banana plantations [23]. The ecological cultivation mode of rubber—*Alpinia oxyphylla* tree and the ecological cultivation mode of rubber—*Homalium ceylanicum* were similar to those of sweet potatoes interplanted between rows in banana plantations [23]. Composite *Alpinia oxyphylla* tree and the ecological cultivation mode of rubber—*Homalium ceylanicum* biased the soil aggregates towards micro agglomerates probably because of the root morphology characteristics such as total root length, total root surface area, and total root volume were positively correlated with soil aggregate stability indicators $R_{0.25}$, MWD and GMD [19]. It may also be related to environmental climate. It has been shown that long-term warming increased the turnover rate of 0.25 - 2 mm macroaggregates in soil aggregates from alpine meadows in Tibet, and the decrease in the mass fraction of soil aggregates led to a decrease in the geometric mean diameter (GMD), mean weight diameter (MWD), and the specific gravity of macroaggregates, which reduced aggregate stability [21].

In this study, a preliminary study on the effects of different ecological complex cultivation patterns on the water stability of soil aggregates in rubber plantations was carried out only in the rainy season without considering the changes in the dry season, and the effects of different ecological complex cultivation patterns on the water stability of soil aggregates in rubber plantations in the seasons need to be further explored in the future.

5. Conclusions

In this study, the conclusions obtained from the data are as follows.

1) In shallow (0 - 20 cm) soil under different ecological cultivation modes, the ecological cultivation mode of rubber—*Alpinia oxyphylla* and the ecological cultivation mode of rubber—*Phrynium hainanense* plantation lead to the development of soil aggregates dominant size class to large aggregates size class. However, the opposite was the ecological cultivation mode of rubber—*Homalium ceylanicum* plantation.

2) In deeper (20 - 40 cm) soils, the ecological cultivation mode of rubber—*Phrynium hainanense* plantation resulted in the development of soil aggregate dominance to large aggregate size classes.

3) In two depths of soil, in the ecological cultivation mode of rubber—*Alpinia oxyphylla* plantation and the ecological cultivation mode of rubber—*Homalium ceylanicum* plantation, the composite ecological cultivation mode had lower values of $R_{0.25}$, MWD, and GMD than the rubber monoculture mode; while the ecological cultivation mode of rubber—*Phrynium hainanense* plantation was higher than that of rubber monoculture, but all of the above did not reach the level of significant difference.

Founding

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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