Heliyon 10 (2024) e30550

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Impacts of different slash disposals on soil and water erosion of high-intensity management Eucalyptus grandis × urophylla plantation

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A R T I C L E I N F O

Keywords:
Soil and water erosion
Soil property
Rainfall-runoff
Path analysis
Slash disposal methods

A B S T R A C T

Background: The slash disposal-burning forest-in high-intensity management Eucalyptus grandis × urophylla plantation has accelerated soil degradation.
Statement of the problem: Slash disposals is a contributing factor, but its specific role in the correlation between rainfall-runoff and soil erosion remains elusive.
Objectives: his study investigated the characteristics of rainfall-runoff and soil erosion resistance in different methods of slash disposals in plantation.
Methods: Three methods of slash disposal, namely burning forest (BF), moving away (MA), and spreading evenly (SE), were established. A field simulation experiment of rainfall was conducted, and path analysis was used.
Results: The findings revealed that the water holding, infiltrating properties and the time the rainfall-runoff generated of SE were increased by approximately 10~20 %, 100 %, and 80 %, respectively, compared with BF and MA. Water loss, soil loss and nutrient loss were significantly reduced by 62.23 % and 61.56 %, 69.06 % and 49.55 %, and 58.8 % and 65.42 % in SE and BF compared to MA. Path analysis suggested that different from BF and MA, the correlation between soil water properties and rainfall-runoff factors in SE was weakened, simultaneously considering the result that SE had the lower proportions of silt for sediment component (75.31 %), it stabilized the soil structure.
Conclusions and prospect: Consequently, SE mitigated the erosion force by reducing rainfall-runoff and enhancing the anti-erosion of soil through improved water properties, making it a viable slash disposal. This work provides a detailed description of the soil erosion characteristics of plantation, including water, soil, and nutrient losses caused by rainfall-runoff, as well as the soil anti-erosion due to different slash disposals. These findings offer valuable insights for the management of high-intensity Eucalyptus grandis × urophylla plantations.

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https://doi.org/10.1016/j.heliyon.2024.e30550
Received 22 January 2024; Received in revised form 26 April 2024; Accepted 29 April 2024
Available online 1 May 2024
2405-8440/

1. Introduction

High-intensity management of Eucalyptus grandis × urophylla (*E. urophylla*) plantations can result in soil quality degradation [1,2] and increased soil and water erosion [3,4]. The traditional practice of slash disposal, burning forest (BF), is considered a critical factor in this degradation [5]. Slashes are what is left over after the timbers have been taken away, and burning them eliminates all combustibles and eradicates most pests on the plantation, while also generating a large amount of nutrients through the combustion of the biomass. Although burning forest is a cost-effective and efficient solution to remove slashes [6], the high temperature generated by the burning of the slashes damages the soil structure and exposes the soil surface leading to increased soil and water erosion [7–9]. To reduce soil and water loss and promote sustainable plantation development, alternative methods for disposing of slash, such as leaving it in the plantation or removing it from the plantation, are being explored as substitutes for BF. Previous studies have shown that leaving the slashes in the plantation significantly increases the content of soil organic nitrogen and the percentage of its active components [10] as well as the availability of phosphorus [11]. Therefore, it contributes to the improvement of soil nutrients and enzyme activity [12]. It has a positive impact on the content and stability of soil organic carbon, which helps to improve soil nutrient availability and soil quality [13]. However, removing the slashes from the plantation may result in the poorest soil physical and chemical properties, and the growth of saplings [14]. Therefore, removing the slashes from the plantation might be the least desirable method for slash disposal. Therefore, existing studies focus on the effects of various methods of slash disposal on soil fertility, but they do not adequately address the water-related aspects of soil and the characteristics of rainfall runoff.

Soil and water erosion in the plantation is mainly the result of the soil's susceptibility to erosion [15] in the face of rainfall-runoff erosive force [16]. Heavier rainfall-runoff carries more sediments [17–19]and soil nutrients are lost simultaneously with water and sediments, either by adhering to sediment [20] or by dissolving in the water flow [21]. Therefore, indicators such as water loss (WL), sediment loss (SL), nutrient loss, and the time the rainfall-runoff is generated are chosen to describe the characteristics of rainfall-runoff. Water holding and infiltrating features are two key indicators used to assess soil erosion resistance [22]. The recognized indicators of water holding features include mass moisture content (MMC), volumetric moisture content (VMC), maximum water-holding capacity (MaxWHC), capillary water-holding capacity (CWHC), and minimum water-holding capacity (MinWHC). The indicator hydraulic conductivity (K) value is used to measure water infiltrating features, while soil macroporosity (MAP) serves as the main channel for water preferential flow in soil, significantly impacting water infiltrating of soil [23,24].

Slash disposal methods, named spreading evenly (SE) and moving away (MA), are cost-effective, efficient, and achievable. The BF method, which is expected to be replaced, has also been selected. It was hypothesized that (1) different methods of slash disposal would alter soil textures, thereby impacting the characteristics of rainfall-runoff. (2) The SE effectively extends the duration of rainfall-runoff generation, reduces water and sediment loss, and mitigates the impact of changing soil texture and water flow force on soil and water erosion, thereby effectively conserving the soil and water for the plantation. (3) Both BF and MA exacerbate soil and water erosion, but their rainfall-runoff characteristics differ: BF is expected to result in the greatest nutrient loss, with a higher clay content in sediment, while MA is expected to have higher water and sediment loss, with a higher sand content in sediment.

To verify the above assumptions, an experimental plot was established in the E. urophylla plantation at the East Branch of Guangxi State owned Daguishan Forest Farm (GSDFF). The surface soils were sampled [25] to analyze their water holding and infiltrating

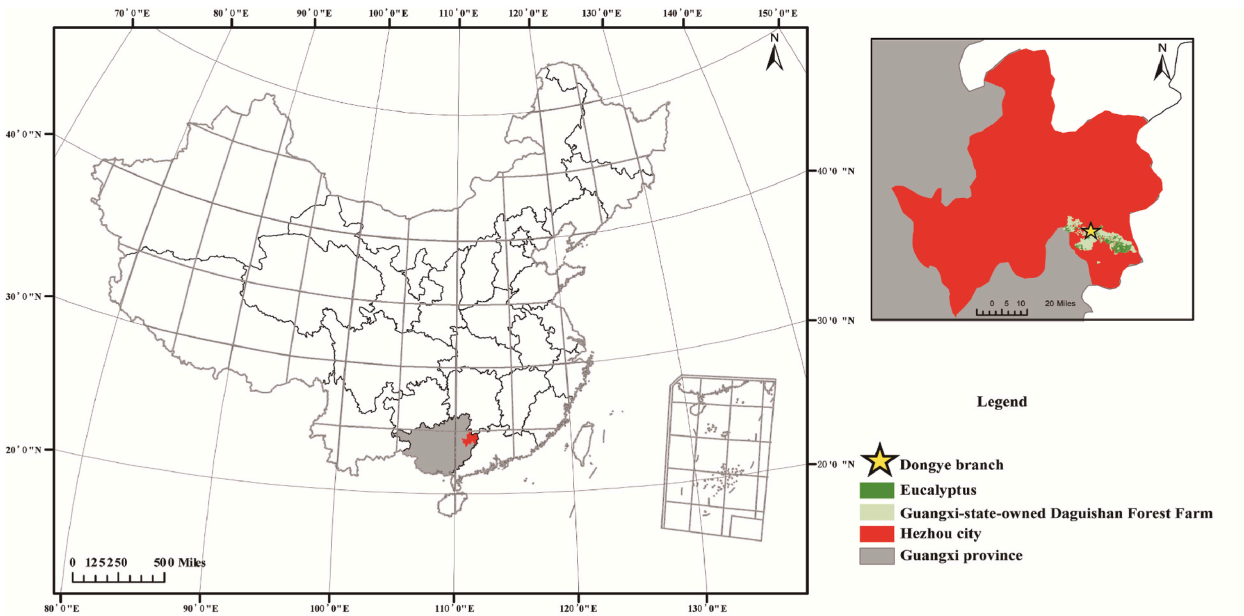

Fig. 1. Location map of the study area for the experimental plantation located at East Branch of Guangxi state owned Daguishan Forest Farm (GSDFF), Hezhou City, China.

characteristics. A field artificial simulation experiment of rainfall was conducted to collect and analyze the indicators of rainfall-runoff. Path analysis was used to clarify the correlations among the aforementioned factors. The objectives of this study are: (1) to clarify the effects of different slash disposal methods on soil properties and rainfall-runoff characteristics and (2) to reveal the mechanism of soil and water conservation in E. urophylla plantations. This study was conducted to enhance understanding of the relationship between various methods of slash disposal and their impact on soil and water conservation in plantations. It also helps to assist forest producers in developing ecologically sound forest management practices to achieve sustainable development in high-intensity Eucalyptus plantations.

2. Materials and methods

2.1. Description of the study area

The experimental site is located in GSDFF, Hezhou City, China [26] (24°7′4″–24°7′18″N and 111°42′59″–111°43′7″E) (Fig. 1). The area is at the boundary of the middle and south subtropical parts and has a subtropical humid monsoon climate with an annual mean rainfall of 2056 mm. According to data from the Hezhou Meteorological Bureau the annual mean temperature is 19.3 °C, the maximum temperature is 39.7 °C, the minimum temperature is −2.4 °C, and the annual accumulated temperature is 6243 °C. The average annual rainfall is 2056 mm, and the annual evaporation is 1275 mm. The average relative humidity is 82 %, the annual average number of sunshine hours is 1600–1800, and the frost season lasts for 12 days. The experimental sites are located in hilly areas with altitudes ranging within 200–300 m. The area of the experiment point is 330 ha, and the altitude is 250–280 m. The soil type of the study area is alliticudic ferrosols, which were derived from Cambrian sandstone according to the Chinese Soil Taxonomic Classification. The thickness of the soil is approximately 80 cm. The *E. urophylla* plantation was established based on the local evergreen broad-leaved forest in 2002. *E. urophylla* (DH32-29) was planted with a row spacing of 2 m × 3 m and a planting density of 1665 plants ha per hectare and first felled in 2007, reestablished by sprout, felled for the second time in 2012, reestablished by sprout, felled for the third time in 2016, reestablished by sprout, and felled the fourth time in August 2022.

2.2. Selection of sample land

Three sample lands (20 m × 20 m) [27] with a 20° slope and comparable altitude, soil, climate, and other factors were selected in the plantation just behind the felling. For the initial step, SE was selected in two of the sample lands with spreading the slashes evenly in the sample lands. MA was selected in the third sample land with moving all the slashes away. For the second step, a moderate-intensity fire was used to burn the slashes in one of the SE in January 2023, converting this sample land to BF, while the remaining sample land remains SE. For the final step, three rainfall zones (2 m × 3 m) [28] were created in sample lands SE, BF, and MA following the settings (Fig. 2).

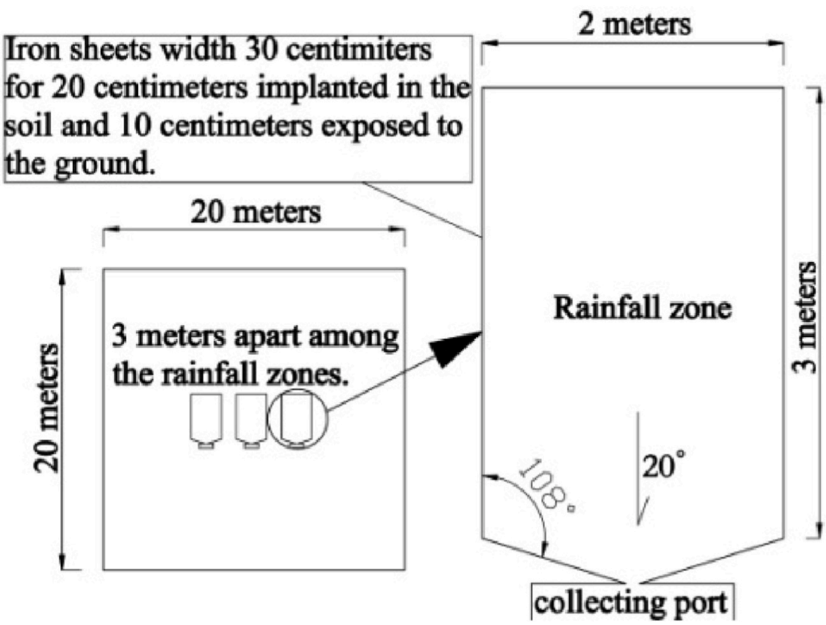

Fig. 2. Pattern and size of rainfall zones in the experimental sample lands.

2.3. Soil sampling and soil indicator determination

The pretreatment of three consecutive days of drip irrigation, which did not wet the slashes and ensured that the soil was completely moist, for each rainfall zone was conducted in January 2023 to counter the four consecutive months of drought of the plantation since August 2022. Soils were collected using six ring knives (500 cm^3) in each rainfall zone 12 h after pretreatment, when the soil water content was stable, and then taken to the laboratory. Three ring knives were used to determine soil hydraulic conductivity using the cutting ring method [29], while the other three were used to determine soil water-holding indicators using the drying method [30] such as MMC, VMC, MaxWHC, CWHC, MinWHC, and MAP.

2.4. Rainfall-runoff collection and rainfall-runoff index determination

The field-simulated experiment of rainfall was conducted using a self-made device (The rainfall height was 3 m, the intensity ranged from 25 mm/h∼150 mm/h, and the uniformity coefficient [31] was 82 %, Fig. 3) just behind the ring knife. The simulated rainfall intensity was 120 mm/h, as per the data from the local hydrological station. This is approximately equivalent to the 1-h rainfall for a 100-year return period, which is 107 mm/h, and the duration of the rainfall was 30 min. The timing started when the rainfall began, and the runoff time (T) was recorded as the rainfall-runoff was generated. The rainfall-runoff was collected in a plastic bottle with a capacity of 1000 mL (Gb was recorded as its weight when completely dry) every 3 min from the start of the rainfall-runoff until it ceased. Therefore, the entire rainfall-runoff process was recorded for ten 3-min, namely 1st 3 min, 2nd 3 min …... 9th 3 min and 10th 3 min. Two scenarios were possible: First, the bottle was not filled in 3 min, and the weight (G) was recorded as the rainfall-runoff for the 3-min period. Secondly, the bottle was filled in less than 3 min. It was then weighed, and the time it took to fill the bottle was recorded. The weight (G) as the rainfall-runoff of the 3 min was converted based on the proportion between the time and 3 min.

The supernatant of the rainfall-runoff was taken after it was stewed for 12 h for the determination of water-soluble phosphorus (WP) using ammonium molybdate spectrophotometry, water-soluble nitrogen (WN) using an automatic kjeldahl apparatus, and water-soluble potassium (WK) using flame atomic absorption spectrophotometry. The remaining rainfall-runoff was dried in a baking oven at 60 °C. The weight (Gs) was recorded when completely dry. Then, the weight of SL should be equal to Gs−Gb, and the weight of WL should be equal to G−SL. The completely dried sediment was taken, ground, and filtered through a 2 mm sieve to determine its components. A laser particle size analyzer was used to classify the sediment content based on diameter, with 0–2 μm identified as clay, 2–50 μm as silt, and >50 μm as sand. The Kjeldahl method was employed to measure the total nitrogen content (TN), while the digestion and Mehlich 3 methods were used to determine the total phosphorus content (TP) using a Smartchem 200 Discrete Chemistry Analyzer (West Co. Scientific Instruments, Brookfield, CT, USA). The total potassium content (TK) was determined using digestion and

Fig. 3. The self-made device for the field-simulated experiment of rainfall.

Mehlich 3 methods with a flame photometric detector.

2.5. Path analysis

Factor analysis was used to categorize the soil indicators MMC, VMC, MaxWHC, CWHC, and MinWHC as water holding feature (WHF) and MAP and K value as water infiltrating feature (WIF). The values of WHF and WIF were calculated by multiplying the component score coefficient of the indicators classified into them by the value of the respective indicators resulting from the factor analysis, and then adding them together as a factor in path analysis. Path analysis was employed to uncover the causality and the relationships between WHF, WIF, T, WL, SL, WN, WP, WK, TN, TP, TK, and sand content of the sediment (SC). WHF and WIF may affect all rainfall-runoff factors, while WL may impact SL, WN, WP, WK, and SC. SL may affect TN, TP, TK, and SC. Then, regression analysis was conducted for each potential influence to identify the path with a significant correlation ($p < 0.05$).

2.6. Statistical analysis

Analysis of Variance (ANOVA) ($p < 0.05$) was utilized to analyze the soil water holding and infiltrating properties, and path analysis ($p < 0.05$) was employed to examine the correlation among all the factors. Statistical Package for the Social Sciences (SPSS) software, version 19.0, IBM, New York, USA was used to perform statistical analysis ANOVA. Excel 2010 and AutoCAD 2008 (Autodesk, Inc.) were used to create graphs and figures.

3. Results

3.1. Soil water properties

The water holding and infiltrating indicators of SE are significantly better than those of BF and MA (Fig. 4, $p < 0.05$). The indicators of SE are significantly higher than those of BF and MA in VMC (14.78 %, 19.47 %), MaxWHC (13.88 %, 18.66 %), CHWC (10.44 %, 11.94 %), and MinWHC (11.51 %, 12.80 %), respectively (Fig. 4A). The K value of MA stabilized at 0.34 cm/min after 65 min, while that of BF remained at 0.41 cm/min after 55 min, and the two are 46.21 % and 55.35 % of that of SE (0.73 cm/min), respectively (Fig. 4B).

3.2. Water loss and sediment loss of rainfall-runoff

The WL of the three slash disposal methods increased over time and stabilized around the 8th 3 min, and the WL of MA is significantly higher than those of SE and BF (Fig. 5A). The time of rainfall-runoff generation of SE was significantly later than that of BF, and BF was significantly later than that of MA (Fig. 5C). The WL of MA is 3402.72 g in the 1st 3 min after the rainfall-runoff generated, which is 5.17 times that of BF (657.8 g) and 13 times that of SE (261.28 g). It rapidly increased to 4899.52 g in the 2nd 3 min, an increase of 44 %, and then steadily rose to 7594.23 g by the 8th 3 min. The WL of MA (7594.23 g) and SE (3400 g) reached their maximum at the 8th 3 min, while BF showed a trend of sustained growth to 4117.11 g until the 10th 3 min. The total amount of WL for MA is the largest (61,362.52 g), followed by BF (23,590.54 g), and SE (23,177.18 g) the least.

The SL of MA was significantly higher than that of BF, which was significantly higher than that of SE at the 1st 3 min, and the 2nd to the 10th 3 min, all the three slash disposal methods were at the same level and decreased slowly (Fig. 5 B). The SL of MA was 248.88 g in the 1st 3 min, which was 3.8 times BF (64.67 g) and 19.47 times SE (12.78 g), and the BF was 5 times SE. There was an 80.57 % decrease in MA (48.36 g) and a 185.48 % increase in SE (36.49), and all the three slash disposal methods were approximately at the same level by the 2nd 3 min. As the three slowly decreasing to the 10th 3 min, BF (16 g) and MA (16 g) were 4 times SE (4 g). The total amount of SL is MA (458.86 g) the largest, followed by BF (231.48 g), and SE (141.98 g) the least.

The sediment content in the WL of the three slash disposal methods showed a trend from high to low over time and decreased rapidly to the 3rd 3 min since the rainfall-runoff was generated, followed by a slower decrease (Fig. 5C). The sediment content of BF

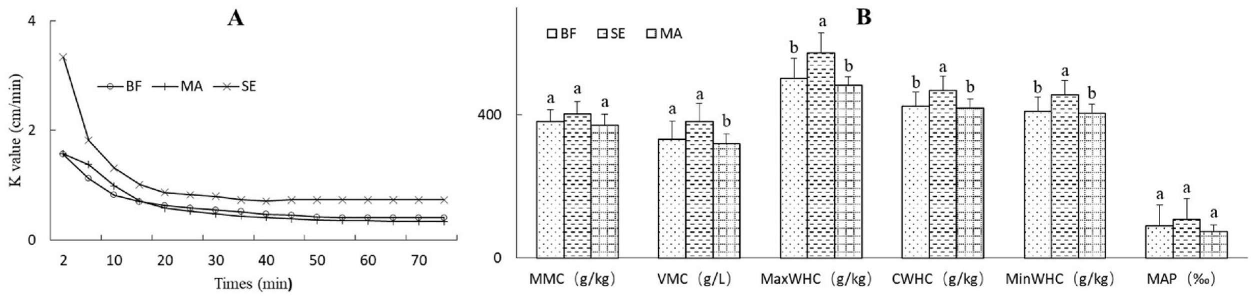

Fig. 4. Water holding features (B) and infiltrating features (A) under different slash disposals in GSDFF in China. While BF means burning forest, SE means spread the slashes evenly, and MA means move the slashes away.

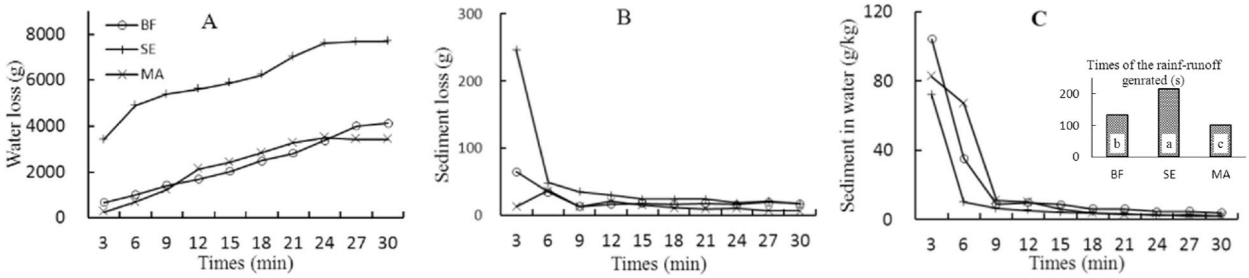

Fig. 5. Regularities of (A) water loss, (B)sediment loss, and (C) sediment in water for different slash disposals in GSDEF in China. While BF means burning forest, SE means spread the slashes evenly, and MA means move the slashes away.

(104.15 g/kg) in the 1st 3 min after the rainfall-runoff was generated was significantly higher than that of MA (82.62 g/kg) and SE (71.63 g/kg). BF and SE decreased to 35.35 g and 9.96 g, respectively, representing reductions of 66.07 % and 86.09 % in the 2nd 3 min, while MA decreased to 67.08 g/kg, reflecting an 18.81 % reduction. BF and MA decreased to 8.8 and 11.03 g/kg, respectively, and SE decreased to 6.5 g/kg in the 3rd 3 min, followed by a gradual decrease to BF (4.01 g/kg), MA (2.18 g/kg), and SE (1.83 g/kg).

3.3. Sediment components of rainfall-runoff

Silt is the primary component of the sediment, and the proportion of sand in BF is significantly lower than those of MA and SE (Fig. 6). The silt content in BF (78.34 %), SE (75.31 %), and MA (74.27 %) accounts for three-quarters of the sediment. The sand content in BF (9.29 %) is notably lower than those of MA (13.48 %) and SE (13.74 %), while the clay content in BF gradually increased from the start (7.8 %) to the end (11.5 %) of the rainfall-runoff, in contrast to the consistent levels in MA (12.25 %) and SE (10.96 %).

3.4. Nutrient loss with rainfall-runoff

The nutrients are mainly lost through WL, the total nutrient loss for MA is significantly greater than those of SE and BF, and the nutrient loss with SL of BF is significantly greater than those of SE and MA (Figs. 7 and 8). WN of BF, SE, and MA decreased to 7.83 %, 50.58 %, and 64.83 %, and WK decreased to 52.19 %, 15.26 %, and 3.38 % from the 1st 3 min to the 3rd 3 min after the rainfall-runoff was generated. The nutrients are mainly lost with SL except for the K element with WL. The total nutrient loss for BF, SE, and MA are

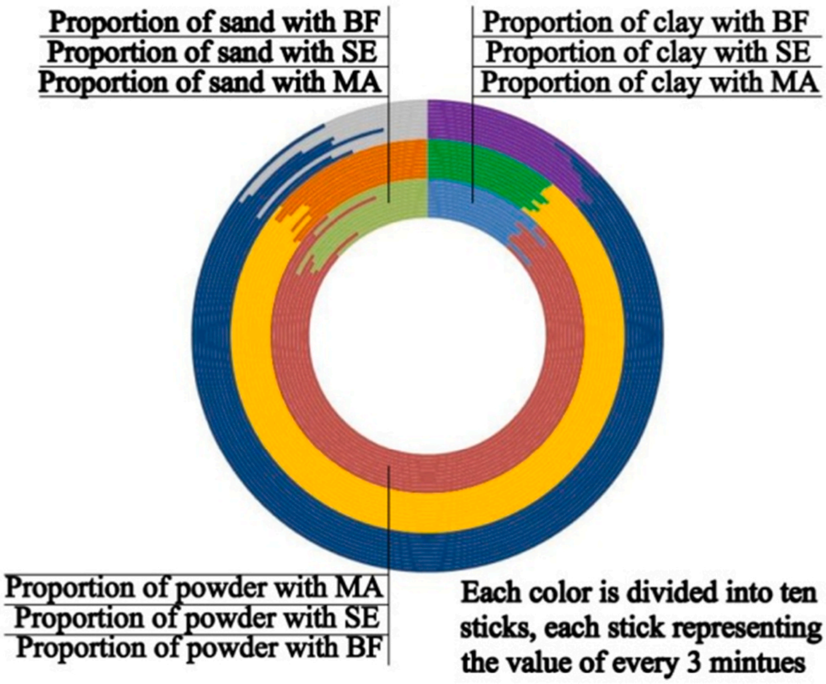

Fig. 6. Characteristics of soil particles for different slash disposals in GSDFF in China. While BF means burning forest, SE means spread the slashes evenly, and MA means move the slashes away.

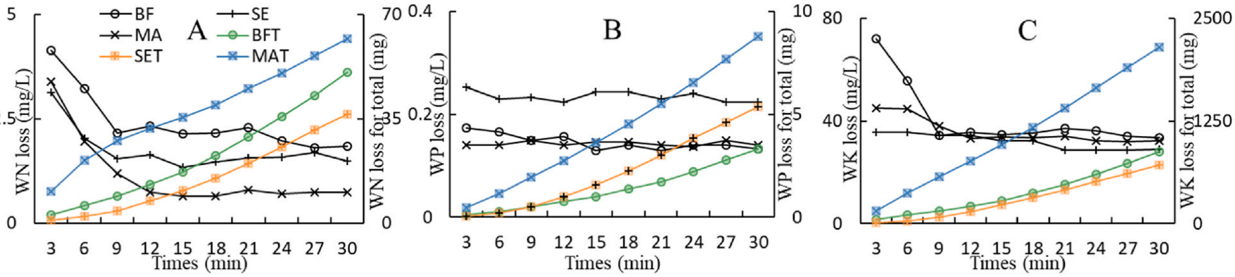

Fig. 7. Nutrients loss with water loss for different slash disposals in GSDFF in China: (A) WN loss and its total, (B) WP loss and its total, and (C) WK loss and its total in mg/L against time in minute. While WN means water-soluble nitrogen, WP means water-soluble phosphorus, WK means water-soluble potassium, BF means burning forest, SE means spread the slashes evenly, MA means move the slashes away, BFT means the nutrients loss for total under the conditon burning forest, SET means the nutrients loss for total under the condition spread the slashes evenly, and MAT means the nutrients loss for total under the condition move the slashes away.

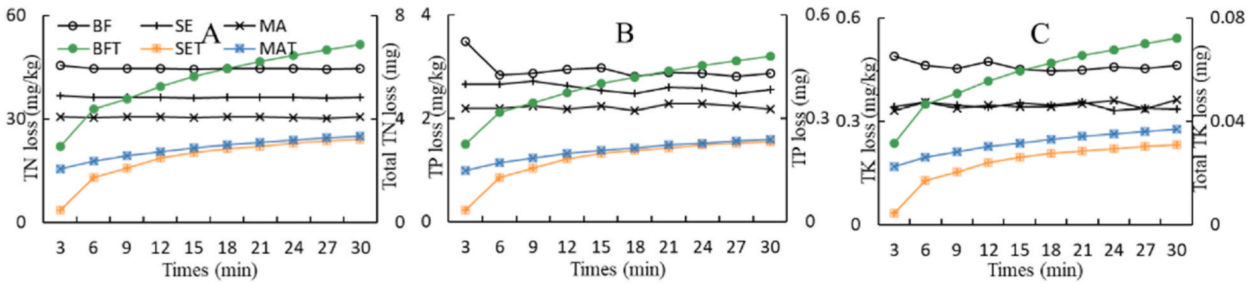

Fig. 8. Nutrients loss with sediment loss for different slash disposals in GSDFF in China: (A) TN loss and its total, (B) TP loss and its total, and (C) TK loss and its total in mg/Kg against time in minute. While TN means the total nitrogen content, TP means the total phosphorus content, TK means the total potassium content, BF means burning forest, SE means spread the slashes evenly, MA means move the slashes away, BFT means the nutrients loss for total under the conditon burning forest, SET means the nutrients loss for total under the condition spread the slashes evenly, and MAT means the nutrients loss for total under the condition move the slashes away.

WN (50.47, 36.46, and 66.77 mg) (Fig. 7A), WP (3.32, 5.39, and 8.78 mg) (Fig. 7B), and WK (873.67, 710.25, and 2151.74 mg) (Fig. 7C), which are significantly higher than TN (6.87, 3.22, and 3.34 mg) (Fig. 8A), TP (0.48, 0.23, and 0.24 mg) (Fig. 8B), and TK (0.07, 0.03, and 0.04) (Fig. 8C). BF experiences the most nutrient loss with SL and has the highest nutrient content in the sediment, while MA experiences the most nutrient loss with WL.

3.5. Path analysis for soil and water erosion

Different slash disposal methods alter the path of soil and water erosion, and the impacts on soil properties vary significantly among the three methods (Fig. 9). WL significantly affects nutrient loss and SL (positive correlation) in the three treatments. The WHF of BF significantly affects WL (negative correlation), and then WL significantly affects WN, WK, and SL (positive correlation). Additionally, SL significantly affects WN (positive correlation). WHF and WIF of MA have a significant negative correlation with SC. WL significantly affects WN, WK, and SL (positive correlation) and WP (negative correlation), and then SL significantly affects WN and WP (positive correlation). The WL of SE significantly affects WN and WK (positive correlation) and WP (negative correlation).

4. Discussion

4.1. Water holding and infiltration features

The water holding indicators, including VMC, MaxWHC, CWHC, and MinWHC, as well as the water-infiltrating indicators such as MAP and K values of SE, are significantly better than those of BF and MA (Fig. 4), indicate that SE can significantly enhance the soil water holding and infiltrating features. These results might be attributed to the decomposition of slash, which enhances the soil environment, increases the MAP, and stabilizes the soil structure, thereby enhancing the soil water conservation capacity [23]. Moreover, the presence of the slash on the soil surface effectively reduces soil water transpiration [32] delays soil cracking caused by drought, and prevents significant damage to soil structure. Otherwise, the slash absorbs the water when the rainfall is light, preventing the generation of rainfall-runoff [33] and then helps to prevent water and soil erosion. Water-repellent substances accumulate and solidify on the soil surface in BF [34], while the ashes produced by the fire fill the soil pores, reducing its water holding and infiltrating features [35]. MA exposes the soil surface, accelerates soil weathering, and reduces the stability of soil aggregates [36], thereby

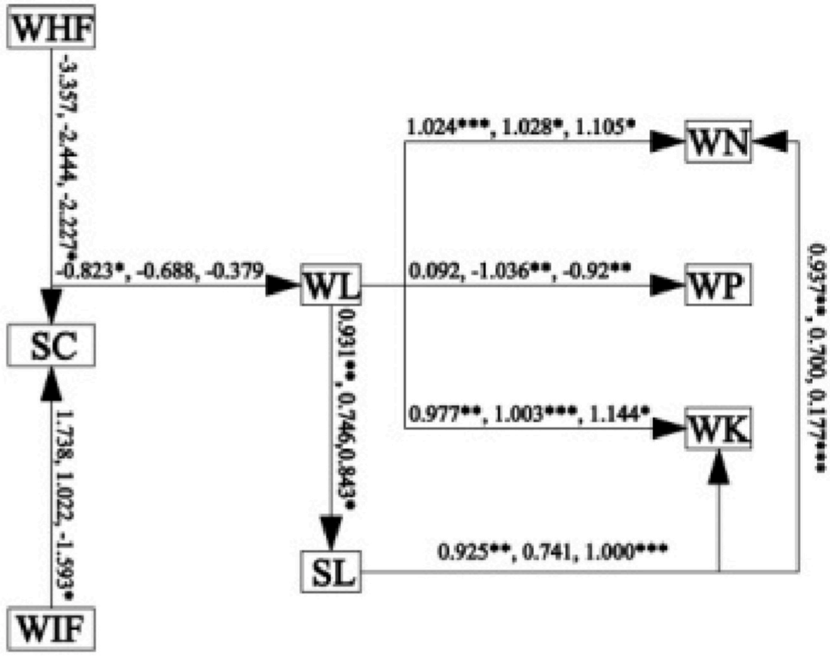

Fig. 9. Path analysis for different slash disposals in GSDFF in China. The numbers above the line mean the coefficients of BF, SE, and MA in turn. "*", "**", and "***" mean significant levels of 0.05, 0.01, and 0.001, respectively.

diminishing the soil water holding and infiltrating features.

4.2. Rainfall-runoff characteristics

The results showed SE significantly delays the time of rainfall-runoff generation and reduces WL and SL, indicating that SE is favorable for soil and water conservation. In the early stages of rainfall, slashes absorb water up to several times its weight [37], significantly delaying the onset of rainfall-runoff and reducing WL. Slashes prevent raindrops from hitting the soil directly by absorbing the impact, reducing the kinetic energy of the raindrops. This effectively maintains the soil structure [38] and enhances soil erosion resistance. When rainfall runoff occurs, the sediments adhere to the small branches and leaves, forming a series of small "dams" on the soil surface. This process makes the soil surface leathery [39], reduces SL [40], enhances water infiltration [41], slows water flow rate, and weakens the hydraulic force of the rainfall-runoff [42], ultimately conserving soil and water.

The sediment component in the SE has the lowest proportion of clay, indicating that SE effectively maintains the soil structure and conserves soil nutrients. The high proportion of clay and silt in BF may be caused by the loss of small particles that are generated by the fire and carried away by the water flow. The loss of these small particles contributes to the roughness of the soil surface [43], which facilitates the generation of a significant water flow [44]. Moreover, the absorption of nutrients mainly relies on silt and clay [45], which implies BF leads to more nutrient loss and significantly reduces soil quality [46]. SE has the lowest proportion of clay, possibly due to the slash covering the soil surface, which reduces the generation of clay from raindrop splash erosion, and the slash can adhere to the clay. A lower proportion of clay results in a more stable crust forming on the soil surface [47]. This suggests that SE is more beneficial for maintaining soil structure and conserving soil nutrients.

The nutrition loss showed that the total nutrient loss of MA is significantly higher than those of BF and SE, whereas the nutrient content of BF is significantly higher than those of MA and SE, suggesting that SE has a positive effect on soil nutrient conservation. Although BF can generate mass nutrients in the short term [48], its high water and sediment content loss (Fig. 5A and C) indicates that BF cannot conserve nutrients. MA experiences the highest nutrient loss due to its greater WL of MA compared to BF and SE This suggests that rainfall runoff is the primary cause of soil nutrient loss. The WP content of SE is significantly higher than those of MA and BF. BF reduces the P element content of soil [49], while the slow decomposition of SE can effectively increase the P element content of soil [50]. SE has a lower nutrient content in water loss and less nutrient loss for total compared to BF and MA.

4.3. Mechanism of soil and water conservation

The correlation between WHF, WIF, SL, and other factors in both BF and MA disappears in SE, indicating that SE alters the soil and water conservation path of the plantation. The reduction of WHF is the primary cause of soil and water erosion in BF, and the mechanism behind this is that the decrease of WHF leads to an increase in WL. Furthermore, SL increases as WL increases. Moreover, the increase in WL and SL leads to an increase in WN and WK (Fig. 9), which is consistent with previous studies [51,52]. The impact of

WL and SL on WN and WK is equally significant in BF because the clay content of the soil is a major factor in nutrient adsorption [53]. Additionally, BF has a higher clay proportion, which enhances the nutrient content in sediment and strengthens the correlation between SL and nutrient losses. The impact of SL on WN is significantly weaker than that of WL in MA treatment due to the lower clay content in MA compared with BF. Soil properties influence the proportion of sand in the sediment in MA. The sand content in sediment is a crucial indicator of soil structure stability [54]. The WL of MA is significantly higher than those of BF and SE, resulting in greater hydraulic erosion force that damages the soil structure and increases the sand content. The interaction between hydraulic erosion force and soil properties has become a critical factor in water and soil conservation. Only WL has a significant correlation with WN, WK, and WP in SE possibly due to the excellent absorption of rainfall and the interception of rainfall-runoff by the slash covering the soil surface [55]. This can significantly enhance the soil water-holding capacity and reduce sediment and nutrient losses, thereby decreasing soil and water erosion [56]. The impact of slash on rainfall-runoff is more significant [57] than that of soil properties and SL. Therefore, replacing them is a significant factor for soil and water conservation. No factors are found to be correlated with factor T in this paper, which contradicts the existing conclusions regarding the correlation between soil properties, slashes [58], and T. The intensity of rainfall is identified as the most critical factor affecting T [59]. This may be attributed to the excessive intensity of rainfall we considered, which could overshadow the influence of other factors on T. WP has a negative correlation with WL in SE, but WP and WL have no correlation in BF and MA. This may be due to the low content of P in the soil of the plantation [60]. Additionally, BF and MA decrease the soil P content. Consequently, there is almost no loss of P element observed with the rainfall-runoff and sediment, which may explain the lack of correlation between the P element and other factors in BF and MA. The SE increases the content of the P element, leading to a significantly higher WP compared with BF and MA (Fig. 7B). However, this increase may not be significant because the P element cannot increase proportionally with the increase of WL, resulting in a negative correlation between WL and WP in SE.

4.4. *Implications for management of E. urophylla plantation*

Conflicting factors indicate that when adopting methods of slash disposal, it is important to consider lower costs, faster wood growth for improved economic benefits, and minimal adverse effects on soil and ecology for sustainable development. In this paper, indicators show that the water holding and infiltrating features, as well as the factors affecting the rainfall-runoff characteristics of MA, are significantly worse than those of the other two. This suggests that moving the slashes away from the plantation is the final option for slash disposal. BF contributes to the accumulation of nutrients in the soil [61]. However, the sediment content in WL is significantly higher than that of SE (Fig. 5C), and there is more severe nutrient and soil loss in WL compared to SE (Figs. 7 and 8). These findings suggest that BF is less effective than SE in conserving nutrients and maintaining soil structure. However, SE requires more effort than BF, and the cost of clearing the stumps while reestablishing the plantation is high. Therefore, SE is recommended for adoption when coppicing regeneration is used to reestablish the *E. urophylla* plantation.

5. Conclusions

The field artificial simulation experiment of rainfall conducted in this study preserved the original condition of the soil and yielded realistic outcomes. The research findings suggest that the method spread evenly outperforms both the method burning forest and move away in terms of water holding and infiltrating features, and rainfall-runoff characteristics. Path analysis revealed that while the method evenly spreading does not replace the crucial role of water flow in water and soil erosion within plantations, it does alter the pathway of soil and water erosion by reducing the correlation between soil water properties and rainfall-runoff factors. Additionally, the method spread evenly diminishes the erosive force of rainfall-runoff by minimizing water loss, weakening the opposing correlation between erosion force and anti-erosion of soil through the overlay of the slashes, effectively reducing sediment and nutrient loss.

Funding

This work was funded by China National Key Research and Development Program during the 14th Five-year Plan Period name 2023YFD2201003, Lichao Wu, LW. Outstanding Youth Scholar Program of Education Department of Hunan Province name 20B605, Lijun Chen, LC. and China Postdoctoral Foundation name 2021M693577, Lijun Chen, LC.

Data availability statement

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Lin Zhang: Writing – original draft, Validation, Software, Formal analysis. **Qinzhan Wu:** Supervision, Investigation. **Kangting Huang:** Resources. **Xiaolong Chen:** Visualization, Validation. **Sen Liu:** Data curation. **Shengyuan Liu:** Validation. **Lijun Chen:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Lichao Wu:** Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank the residents within the Daguishan Farm Division for their hospitality during our fieldwork. The project also benefited from the contribution of the Guangxi Di Yuan Zhi Ben Fertilizer Industry Co., Ltd., Researchers contributing to this project include Yuxing Xu, Yao Huang.

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