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Utilization of Forage Crops as an Effective and Eco-friendly Method for Weed Growth Control and Distribution in an Immature Rubber Plantation

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Abstract

Rubber plantation, especially in the immature phase, is usually infested by various local weed species in the inter-row spaces of the rubber trees. This study aimed to evaluate the distribution of weed species and the growth and yield of forage crops for weed control and management in an immature rubber plantation. The field study was conducted with four treatments of forage crops. The first treatment was a control plot in which local weeds were growing naturally without forage crops. The plot was compared with the other three immature plots wherein native tropical carpet grass (Axonopus compressus), native whip grass (Hemarthria compressa) and high productive yield ruzi grass (Brachiaria ruziziensis) were planted, respectively, in the inter-row of the rubber trees. The study period was split into four seasons: S_0 – January to June 2016; S_1 – July to September 2016; S_2 – October to December 2016; and S_3 – January to March 2017. Results showed that three families of narrow-leaf and nine families of broad-leaf weeds were found in the study area. A large number of common weed families were observed more in the S_3 than those in other seasons. Moreover, all forage crops were effective in suppressing weeds, with ruzi grass demonstrating the highest level of competitiveness and yield among the native forage crops reaching 1.50 Mg ha^{-1} in the S_3. Therefore, implementing an indirect weed control approach using forage crops in rubber plantations could serve as a sustainable and environmentally friendly alternative to chemical herbicides.

***Keywords**:* root competition, rubber-based intercropping system, tropical forages, weed control and management

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1. Introduction

Rubber, a key economic crop in Thailand, is mainly concentrated in the southern regions of the country because of the appropriateness of all-yearround tropical weather and adequate rainfall for growth and high yields (Unjan *et al*., 2017). However, the weather favors not only the rubber trees but also the growth of weeds, especially during the first three years of immature rubber plantations. Therefore, many types of weeds are usually found around rubber plantations (Stür and Shelton, 1990; Ansong *et al*., 2021; Casimero *et al*., 2022). During the immature phase, the small canopy area of rubber plants allows more sunlight throughout the day in the inter-row spaces resulting in favorable conditions for weed emergence and growth. In addition to being a major competitor of immature rubber plants for light, nutrients, and water, they are fast-growing, and their growth harbors pests and insects (Rodrigo *et al*., 2001).

The native weed distributions differ in type and numbers depending on each area's tillage practices and weather. Various native weed species can be found in rubber plantations in different seasons and environments because the native weeds can thrive and adapt naturally well under intense sunlight and high temperatures. For instance, local grasses, legumes, broad-leaf and narrow-leaf species can spread and cover the whole surface of the plantations (Cosentino *et al*., 2014). Similar to some reports from forage grass plantations of tropical carpet grass and whip grass, which were warm-season perennials, high amounts of water had to be managed to fulfill the need of water requirement but not too high that a wetland could occur (Wilson and Ludlow, 1990). In contrast, the ruzi grass could adapt to hot weather and dry conditions because this forage crop could endure dry conditions and compete well with weeds. Some native weeds may be used as a groundcover or forage crops (Uddin *et al*., 2011), particularly for livestock-integrated farms. For example, cows and goats are usually raised in rubber plantations where tropical carpet grass and whip grass widely grow (Chanjula *et al*., 2017). Tropical forage crops like pangola, napier, ruzi and purple guinea contain nutritive values and can be fed as a staple or supplementary food that reduces the malnutrition problems of livestock (MacLaren *et al*., 2019).

In general, weeds present in the field germinating after sowing are controlled effectively with herbicide applications. The conventional weeding methods in immature rubber plantations are the slashing of the weeds and spraying of herbicides in the inter-row spaces between the rubber trees (Liu *et al*., 2019). However, in chemical weeding, the application rates and types of herbicides have currently been controlled and inhibited by policy due to the negative effects on the agroecosystem components like soil microorganism diversity, soil fertility and growth of beneficial weeds and other associated crops (Carrera *et al*., 2004; Marambe and Herath, 2020). Nevertheless, chemical weeding methods are still widely applied due to the high labor cost of manual weeding (Lancaster *et al*., 2010; Stover *et al*., 2017).

Cover or forage crops are recommended in weed control without applying chemical herbicides in field crop plantations as a sustainable agricultural practice (Jabran and Chauhan, 2018; Haramoto and Pearce, 2019). Cover crops could provide excellent weed suppression, minimize herbicide applications and increase the competitiveness of primary crops over weeds (Carrera *et al*., 2004). Some forage crops showed effective reductions in narrowed and broadleaved weed populations and significant suppression of most grass species (Schoofs and Entz, 2000).

Understanding root competition is essential to assess the interactions between crop plants and weed communities. For example, the size of root systems increases when different cultivated plant species grow in the same area, such as the response of maize to below-ground competition with weeds (Britschgi *et al*., 2013). The spatial distribution of forage roots, interacting with rubber trees, may then further the understanding and management of forage crops. Root distribution indicates crop growth and yield efficiency because roots are the primary below-ground vegetative part for seeking water and nutrient in the soil (Li *et al*., 2006). Several studies have shown that total root length was positively correlated with root size and biomass (Adu *et al*., 2014; Saelim *et al*., 2019). Studies on crop roots without root damage have usually relied on minirhizotron combined with root photo shoots through transparent acrylic tubes inserted into the roots for a continuous, fast and very accurate follow-up of their development and growth.

In an immature rubber plantation, herbicide application is commonly employed to manage weeds (Ansong *et al*., 2021), while cover crops and annual intercrops serve to control them and reduce soil erosion (Liu *et al*., 2019), and potentially increase local household food security (Hondrade *et al*., 2017). Given concerns about the use of chemical herbicides in farming systems (Casimero *et al*., 2022), exploring biologically and eco-friendly approaches to controlling weed distribution is crucial. Therefore, manipulating forage crop integration as the rubber-based intercropping system presents a promising strategy to achieve this goal and minimize reliance on herbicides.

This research aimed to study the contribution of forage crops in weed control and the root growths of forage crops and rubber trees seasonally in an immature rubber plantation. The findings of this study would support the reduction in chemical herbicide applications for the sustainable agroecosystem of the rubber plantations and create on-farm income for rubber farmers from the immature rubber plantation.

2. Methodology

2.1 Experimental Site Description

An experiment was conducted at a farmer-owned immature rubber plantation in Namom District, Songkhla Province, Thailand (6° 56’ 30” N, 100° 33’ 14” E, 53 m above mean sea level) from January 2016 to March 2017. The data collection was carried out seasonally in four periods during the study: January 2016 to June 2016 (S_0); July 2016 to September 2016 (S_1); October 2016 to December 2016 (S_2); and January 2017 to March 2017 (S_3).

The area of the experimental farm was around 1,920 m^2 consisting of about 100 trees. The size of each of the sixteen experimental plots was 6 x 20 m^2. The rubber trees in the experimental farm were clone RRIM 600, aged two years and planted in 3 x 6-m spacing. The stem diameters of the rubber trees measured at the breast height (150 cm from the ground) ranged between 3.5 and 4.2 cm at the beginning of the experiment. A study was carried out regarding weed distribution and density by naturally occurring species under the study areas. In each experimental plot, weeds were tilled and removed by applying herbicide (glyphosate 48% SL) to maintain a weed-free situation after the field preparation. In weed control by the forage crop plots, they were grown and maintained after crop emergence. After germinating, irrigation was used when rainfall did not occur for at least two days. Nitrogen fertilizer urea (46-0-0) was applied at 187.50 kg ha^{-1} after 45 days of regrowth when forage crop cutting (Table 1). A randomized complete block design (RCBD) was used for four treatments of different forage crops with four replications. The first treatment (T_1) as control was a plot of naturally growing weed without being covered by any forage crops. The controlled (T_1) plot was compared with the other three immature plots in which three different forage crops: native tropical carpet grass (*Axonopus compressus*) (T_2); native whip grass (*Hemarthria compressa*) (T_3); high productive yield ruzi grass (*Brachiaria ruziziensis*) (T_4), planted in the inter-row of the immature rubber trees during the summer season (January to March 2016).

Table 1. Soil management practices for preparing the experimental site in an immature rubber plantation

Forage management	Forage plots			
	Control	Tropical carpet grass	Whip grass	Ruzi grass
Sowing	None	Seedlings	Seedlings	Seeds
Soil tillage (time/year)	Once	Once	Once	Once
Herbicide spraying (48% SL)	Once	Once	Once	Once
Watering (sprinkler)	None	2 days interval	2 days interval	2 days interval
Fertilizer application (46-0-0)	None	45 days interval	45 days interval	45 days interval
Harvesting (by grass harvester)	40 days interval	40 days interval	40 days interval	40 days interval

2.2 Weed Distribution and Density Assessment

In each of the 16 plots, weed species grown in the rubber plantation were randomly counted in three selected quadrats (1 x 1 m^2) at maturity and before the harvesting (40 days after cutting). Plant samples were collected separately in the early rainy season from July to September 2016 (S_1), the heavy rainy season from October to December 2016 (S_2) and the summer season from January to March 2017 (S_3). The distributions of weed relative density (RD%) were recorded using morphological techniques (Suwanagul and Suwanketnikom, 2001). The specimens were collected across the rubber inter-rows, photographed and identified in the Plant Ecophysiology Laboratory at Prince of Songkla University, Thailand. Weed names were classified according to their appearance and survival during the seasonal changes from S_1 to S_3.

2.3 Biomass of Forage Crops

At harvesting periods, the total weed biomasses from the treatment plots were determined from the same quadrats at maturity (40-day intervals). The harvested area for crop yield was 120 m^2 during the years 2016 to 2017. The forage crops were cut at ground level and weighed for fresh mass before subsamples were dried in an oven at 65 °C for 72 h. The total yield was then recorded and converted into Mg per ha, which was adjusted at 14% moisture content (Alakali *et al*., 2015).

2.4 Weather and Soil Data Collection under Rubber Plantation

This study monitored the seasonal climatic dynamics with a continuous micrometeorological station installed in the experimental farm. Due to local climate conditions, a weather data logger was used to record the climate variables of each field condition. The hourly datasets for air temperature (°C) and relative humidity (%) were monitored continuously by a micro weather station (H21-002 Data Logger, Onset HOBO, Massachusetts, United States) with a 12-bit temperature smart sensor (S-TMB-M006, H21-002, Onset HOBO, United States) using data assistants (HOBOware® Pro software, Onset HOBO, Massachusetts, United States). To evaluate light intensity variables in the farm, photosynthetically active radiation (PAR) was collected in the inter-row using a light meter (Model No. 748200, Sun System, Canada) between 11:00 AM and 1:00 PM on a sunny day every week. Also, monthly meteorological data (total rainfall and total evapotranspiration) from January 2016 to March 2017 were collected from the Songkhla Agricultural Meteorological Station, Songkhla, Thailand.

Meanwhile, the monthly soil moisture of each plot was determined with the conventional oven method. Soil samples from 0-20, 21-40 and 41-60 cm soil depths were collected, weighed and dried in an oven for 72 h at 105 °C. The dry samples were then reweighed. To analyze some soil properties (i.e., soil total nitrogen, available phosphorus, extractable potassium, soil organic matter and pH) for each depth, the soil samples were collected from the center of each plot at 0-20, 21-40 and 41-60 cm soil depths as described by Jones (2001). All samples were pooled into one sample plot. Cumulative mass soil samples were considered representative samples of the rubber plantation. In this study, the soils in the experimental area at the depths of 20, 40 and 60 cm were mostly classified as sandy loam according to the soil analysis results. Mean soil total nitrogen (Kjeldahl digestion, distillation, and titration method), available phosphorus (Bray II method), extractable potassium (1 N NH4OAc, pH 7 method), soil organic matter (Walkley-Black method), and pH (soil: water = 1:5 by Potentiometric method) ranged 0.02-0.05%, 6.40-14.22 mg kg^{-1}, 25.87-27.04 mg kg^{-1}, 0.37-1.04%, and 4.62-5.49, respectively.

2.5 Root Growth Measurement

The flatbed scanner boxes applied to on-site rhizobox techniques in the field study were used to monitor rubber trees and forage crops' fine root growth (Dong *et al*., 2003). In each of the three replications, two acrylic boxes (5 x 30 x 50 cm^3) were installed vertically at a 90° angle to the ground at 20 cm from the rubber trees. The tops of the boxes were covered with polyvinyl chloride caps and over-wrapped with a black plastic sheet to protect them from sunlight penetrations, which could affect the root growth.

Two months after the installation, seasonal root length and diameter changes were measured monthly by inserting a scanner (Scanjet g3110, HP, United States) into the boxes. All root images were processed using Rootfly software (version 2.0.2) (Birchfield and Wells, 2011) to analyze the root length per area (root length density) at the 20 and 40-cm soil depths. To monitor changes in the fine root over seasonal timing, root samples were taken of new and existing roots on each image every month. The fine root production was evaluated utilizing the approach by Saelim *et al.* (2019).

2.6 Statistical Analysis

All statistical analyses were performed using an open-source software R Analytics (version 3.1.0) (R Core Team, 2014). Data were analyzed using analysis of variance (ANOVA) to evaluate differences between the treatments, and the means were compared using Duncan's new multiple range test (DMRT) at $p \leq 0.05$. The distribution of relative density of weeds, divided into different seasons according to sampling time, was presented using the standard deviation of means to assess the relationships of the data sets.

3. Results and Discussion

3.1 Weather and Soil Moisture under an Immature Rubber Plantation

The light intensity generally ranged from 1,179.20-1,895.86 μmol m^{-2} s^{-1} in the study period. Its trend showed lower values in the rainy season of 2016, especially in June and September 2016. The trend reached the highest in March 2016 and the lowest in September 2016 (Figure 1a). It was observed that the monthly rainfall was high in December and January. It precipitated 665.60 mm in December 2016, and 307.70 and 460.00 mm in January 2016 and January 2017, respectively. Also, the total monthly evapotranspiration had greatly ranged in the summer season of 2016 (February to April) compared with those total monthly rainfall differences. The highest evapotranspiration values were 135.90, 165.50 and 176.70 mm, respectively. Meanwhile, the annual trends of average air temperature and average relative humidity (RH) from S_0 to S_3 ranged generally from 25.86-29.60 °C and 74.86-91.31%, respectively. Moreover, the highest temperatures ranged from July 2016 to

March 2017 (S_1 to S_3) were 36.90-38.10, 35.10-37.10, and 35.90-36.20 °C, respectively. Also, the lowest RH was observed in rainy season S_1 (38.60-43.10%) compared with S_2 (40.80-47.10%) and S_3 (35.70-51.90%) (Figure 1b).

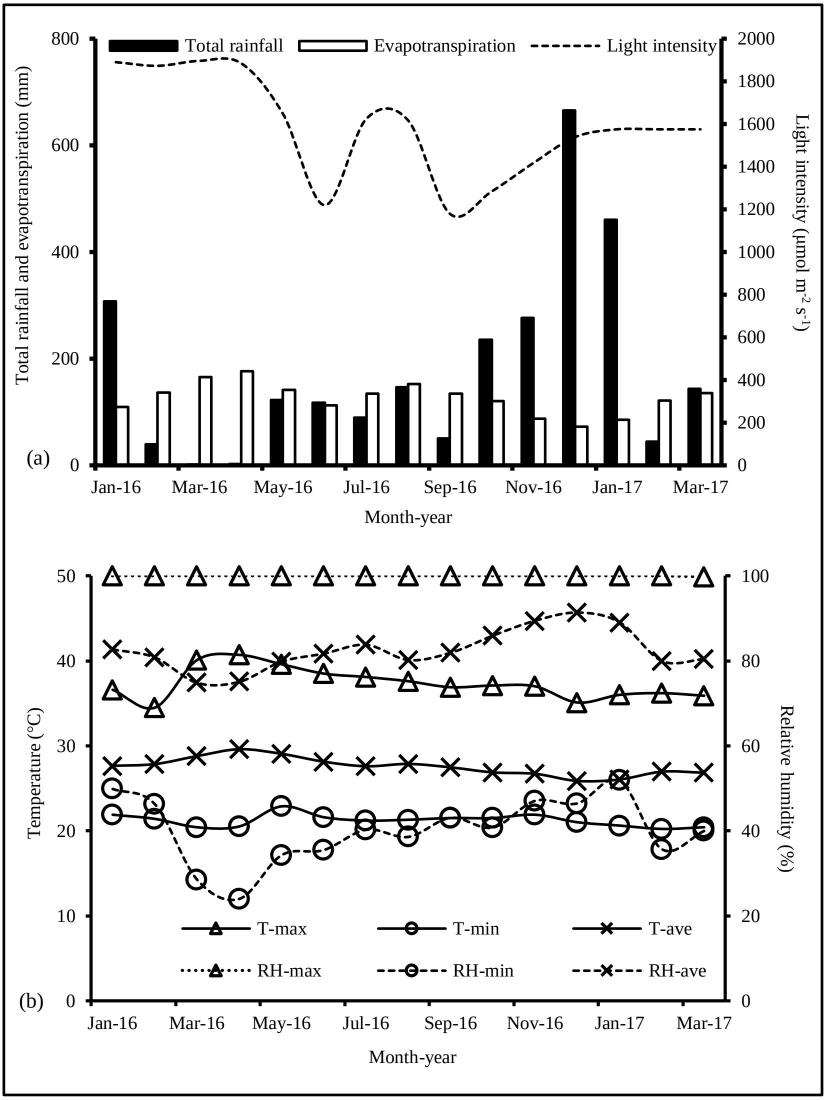
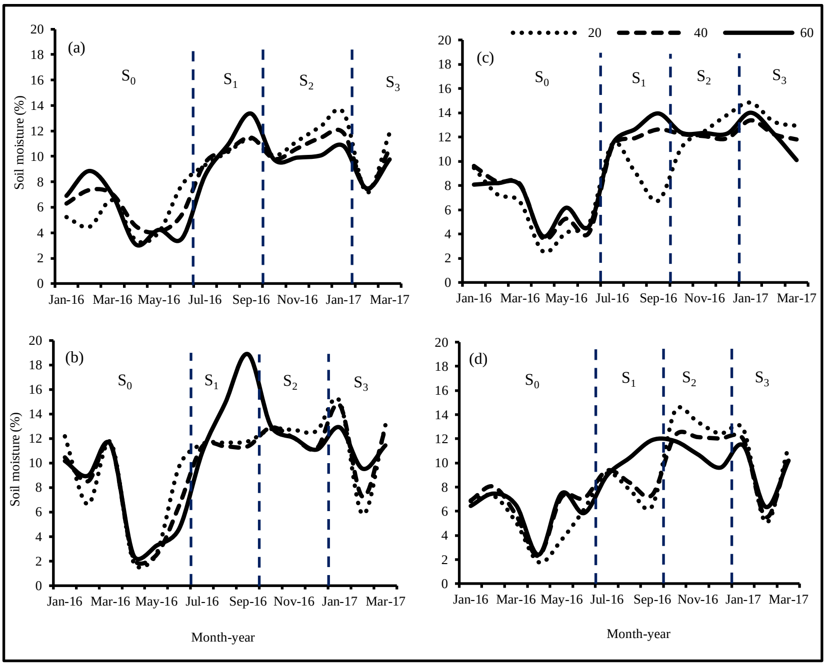


Figure 1. Monthly changes in total rainfall, total evapotranspiration and light intensity (a); monthly changes in maximum, minimum, and average temperatures (T-max, T-min, and T-ave); and monthly changes in maximum, minimum, and average relative humidity (RH-max, RH-min, and RH-ave) (b) in the experimental site from January 2016 to March 2017

Changes in soil moisture content in the different soil depths of the plots are shown in Figure 2 in which the changes generally followed the same trend. In all plots, the lowest soil moisture contents ranged between 1.76 and 4.53% and were found in the different soil layers in April 2016. During the growing seasons, variability in soil moisture dynamics of all forage crops for all soil depths sharply increased until September 2016 (6.44-18.86%) before remaining stable from October 2016 to January 2017 (10.82-15.03%). After that, in the rainy season, the soil moisture contents in all soil depths increased sharply from 6.44% in July to 18.86% in September 2016, followed by relatively stable trends ranging between 10.82 and 15.03% from October 2016 to January 2017. However, dramatic drops in the soil moisture contents in all plots were found in February 2017. Then the contents increased apparently in March 2017 (Figure 2a-2d).



S_0, S_1, S_2 and S_3 are preparation of field experiment, the early rainy, heavy rainy and summer seasons, respectively.

Figure 2. Monthly changes in soil moisture at 0-20, 21-40 and 41-60 cm soil depths in natural weed plots (a), tropical carpet grass plot (b), whip grass plot (c) and ruzi grass plot (d) in a rubber plantation from January 2016 to March 2017

From the weather and soil environmental factors, the study found that the weather in the rubber plantation during the pre-rubber tapping stage was arid.

The higher temperature ranging from 2 to 5 °C with a maximum temperature between 34.50 and 40.70 °C led to a decrease in RH below 40%. The study revealed that climatic factors such as rainfall, rainy days, relative humidity and air temperature significantly influenced potential crop growth (Unjan *et al.*, 2017). The average light intensity throughout the year was also not less than 1,200 µmol m^{-2} s^{-1} (Figure 1). This delivered sufficient light transmission, usually not less than 60%, in the first three years in the rubber trees' inter-row space (Stür and Shelton, 1990; Wilson and Ludlow, 1990; Hondrade *et al.*, 2017). Simultaneously, weather and soil moisture tended to change in the same way in each season. To clarify, there were continuous downpours in the early rainy season from July to September (S_1) and in the heavy rainy season of S_2 until rain reduced in February of S_3. This was a key factor that kept increasing the soil moisture in all treatments (all grass plots of the four treatments), whereas the moisture slightly reduced in summer.

3.2 Relative Density of Weeds as Controlled by Forage Crops

All native weeds were identified and classified into two groups. The study found that narrow-leaved weeds and broad-leaved weeds were most common in rubber plantations. Weed samples were recorded for 12 families, namely Cyperaceae (Cy), Commelinaceae (Co), Poaceae (Po), Amaranthaceae (Am), Asteraceae (As), Boraginaceae (Bo), Capparaceae (Ca), Euphorbiaceae (Eu), Fabaceae (Fa), Mimosaceae (Mi), Phyllanthaceae (Ph) and Rubiaceae (Ru) (Table 2). In terms of relative density among the weed species and forage crops, the most common species were Cyperus iria L., Cenchrus echinatus, Cleome rutidosperma DC., Dactyloctenium aegyptium (L.) Willd., *Digitaria ciliaris* (Retz.) Koel. and *Praxelis clematidea* (Griseb.) R.M. King & H. Rob. *Cyperus iria* L. and *Praxelis clematidea* (Griseb.) R.M. King & H. Rob. were the highest with over 50-75% in weed species richness per forage plot in the tropical carpet grass. *Dactyloctenium aegyptium* (L.) Willd., *Digitaria ciliaris* (Retz.) Koel., *Praxelis clematidea* (Griseb.) R.M. King & H. Rob. and *Cleome rutidosperma* DC. in the whip grass and ruzi grass plots were > 25-50% compared with the other weed species. Meanwhile, the control plots were dominated by Poaceae (*Cenchrus echinatus*) (> 25-50%).

By considering the percentage of the relative density of the number of weeds, it was found that the ruzi grass had the best efficiency in weed distribution control as the weeds found were minimum followed by whip grass with a maximum relative density of some types of weeds not over 50% when compared with tropical carpet grass. It was discovered that the relative densities of some weed species, particularly *Cyperus iria* L. *and Praxelis clematidea* (Griseb.) R.M. King & H. Rob, were high (up to 75%). Since the rubber trees were immature and undeveloped, the leaf area index (LAI) was small. However, this might vary with the time of day. Therefore, the light transmission, which could affect the growth of forage crops, was obtained regularly between the rubber rows during all seasons. Consequently, various weed species could have good self-adaptation and well distribution with highly efficient photosynthesis and plant growth in the environment of immature rubber plantations (Guzzo *et al.*, 2014). Similarly, changes in the rainfall distribution during the year could affect the weed community (Woźniak and Soroka, 2015).

Table 2. Weed relative density of narrow- and broad-leaved weeds controlled by forage crops in an immature rubber plantation

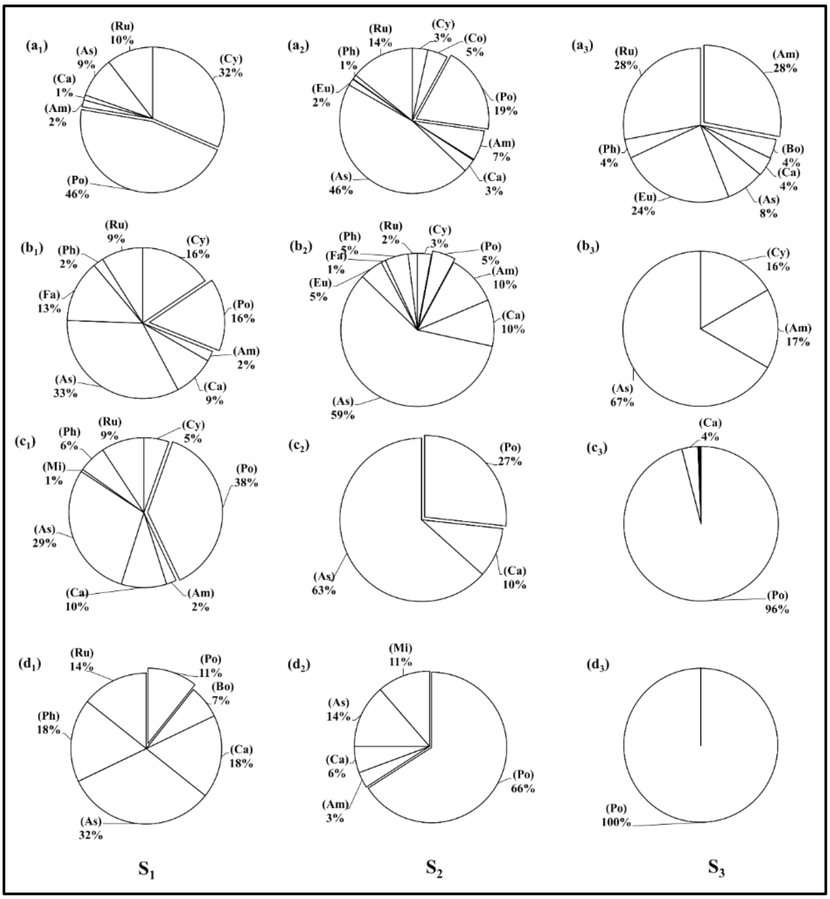
Family name	Scientific name	Relative density (%)			
		Control	Tropical carpet grass	Whip grass	Ruzi grass
Cyperaceae (Cy)	*Bulbostylis barbata* (Rottb.) C.B. Clarke	0-25	0	0-25	0
	Cyperus iria L.	0-25	50-75	0-25	0
Commelinaceae (Co)	*Commelina diffusa* Burm.f.	0-25	0	0	0
Poaceae (Po)	*Axonopus compressus* Beauv.	0-25	0	0-25	0
	Brachiaria mutica	0	0	0-25	0
	Cenchrus echinatus	25-50	0	0-25	0
	Dactyloctenium aegyptium (L.) Willd.	0-25	0	0-25	25-50
	Digitaria ciliaris (Retz.) Koel.	0-25	0-25	25-50	25-50
	Echinochloa colona (L.) Link.	0-25	0	0-25	0
	Eleusine indica (L.) Gaertn.	0-25	0-25	0-25	0-25
	Eragrotis tenella (L.) P. Beauv.	0-25	0	0-25	0-25
	Imperata cylindrica (L.) Beauv.	0	0-25	0	0
	Pennisetum setosum (SW.) R.&S.; *Panicum longisetum* Poir	0-25	0	0-25	0

Table 2 continued.

	Rhynchelytrum repens (Willd.) C.E. Hubb.	0	0	0	0-25
Amaranthaceae (Am)	*Gomphrena celosioides* Mart.	0	0-25	0	0-25
	Stachytarpheta jamaicensis	0-25	0-25	0-25	0
Asteraceae (As)	*Praxelis clematidea* (Griseb.) R.M. King & H. Rob.	0-25	50-75	25-50	25-50
	Tridax procumbens L.	0-25	0	0	0
	Vernonia cineria (L.) Less.	0	0-25	0	0
Boraginaceae (Bo)	*Heliotropium indicum* L.	0-25	0	0	0-25
Capparaceae (Ca)	*Cleome rutidosperma* DC.	0-25	0-25	25-50	0-25
	Cleome viscosa L.	0-25	0	0-25	0-25
Euphorbiaceae (Eu)	*Euphorbia hirta* L.	0-25	0-25	0	0
	Euphorbia heterophylla L.	0-25	0	0	0
Fabaceae (Fa)	*Arachis hypogaea* L.	0	0-25	0	0
Mimosaceae (Mi)	*Mimosa pudica* L.	0	0	0-25	0-25
Phyllanthaceae (Ph)	*Phyllanthus amarus*	0-25	0-25	0-25	0-25
Rubiaceae (Ru)	*Borreria alata* (Aubl.) DC.	0-25	0-25	0-25	0-25
	Borreria laevis (Lamk) Griseb.	0-25	0	0-25	0
	Hedyotis corymbosa (L.) Lamk.	0-25	0	0	0
	Richardia brasiliensis Gomez	0-25	0	0	0

3.3 Weed Distribution Controlled by Forage Crops

The distributions of weed richness were higher in the early rainy season (S_1) and the heavy rainy season (S_2) than those in the summer season (S_3) (Figure 3). The most common weed family that thrived in the tropical carpet grass plots was Asteraceae (As), and its distributions in the S_1, S_2 and S_3 were 33, 59 and 67%, respectively (Figure 3b$_1$-b$_3$). Although Poaceae (Po) was observed to be the most abundant in the whip grass plots in the S_1 and S_3 with 38 and 96% distributions, respectively, its distribution decreased to 27% in the S_2, which was less than that of Asteraceae in S_2 (Figure 3c$_1$-c$_3$). A similar trend was observed in the ruzi grass plots where the Poaceae was the greatest in the S_2 and S_3 with distributions of 66 and 100%, respectively. However, the distribution of Asteraceae (32%) was greater than that of Poaceae (11%) in the S_1 (Figure 3d$_1$-d$_3$). Compared with the control plots, the study found that many weed families (Poaceae, Cyperaceae, Asteraceae, Amaranthaceae, Rubiaceae and Euphorbiaceae) reached their maximum distributions of 46, 32, 46, 28, 28 and 24% in the natural weed plots (Figure 3a$_1$-a$_3$).



S_1, S_2 and S_3 are the early rainy, heavy rainy and summer seasons, respectively.

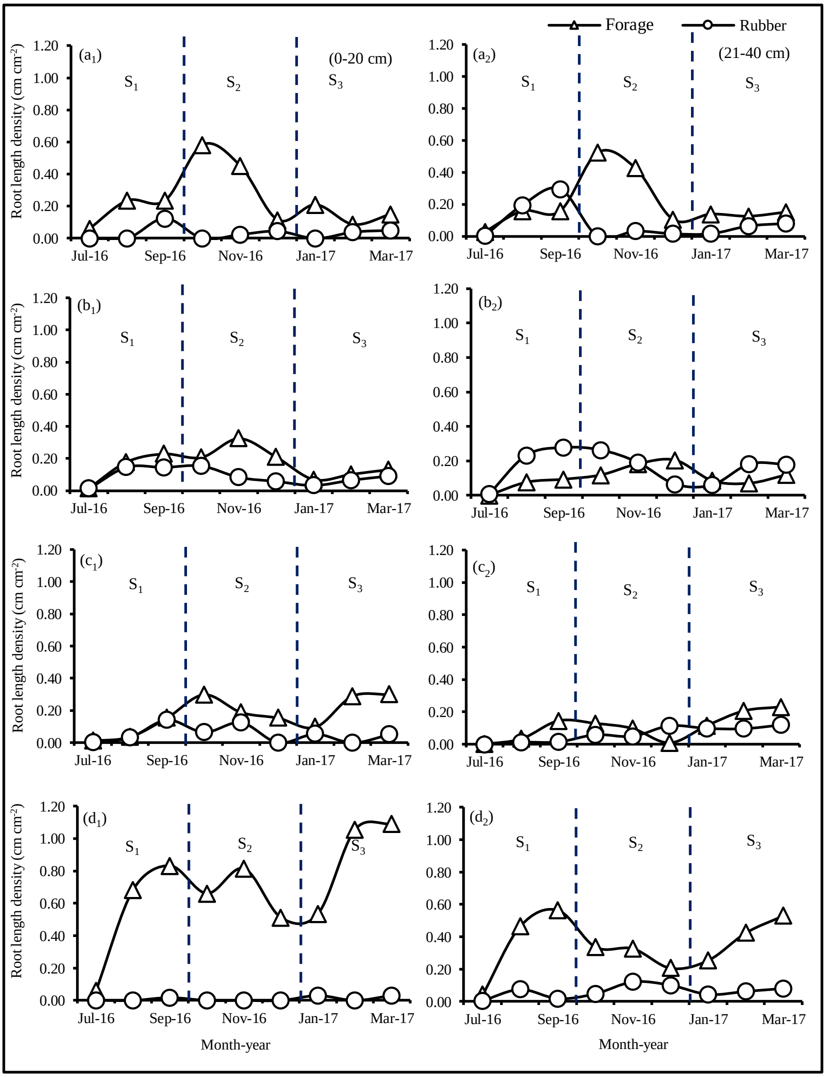
Figure 3. Family of weed distribution in natural weed plots (a$_1$-a$_3$), tropical carpet grass plot (b$_1$-b$_3$), whip grass plot (c$_1$-c$_3$), and ruzi grass plot (d$_1$-d$_3$) in a rubber plantation from January 2016 to March 2017

It was observed that all forage crops in the study could control the weed distributions well but varied from season to season. Specifically, the distributions of both narrow- and broad-leaved weeds were less pronounced in the summer (S_3) than in the rainy season. However, some weeds showed high competition in the forage crop plots. For example, some weeds, belonging to the Poaceae family, were growing widely in the whip grass and ruzi grass plots, while the Asteraceae weed species were found largely in the tropical carpet grass plot. In the rainy seasons (S_1) and (S_2), the study found that the whip grass and ruzi grass tended to control mainly the weeds from the Poaceae and Asteraceae families with the maximum ratios. As the forage crops impacted the weed species and suppressed the weed growths, the study suggested that it could be effectively applied in field crop production as integrated weed management (Meiss *et al*., 2010) although the diversity of weed communities differed among the various cropping patterns and seasons (He *et al*., 2019).

As this study employed no herbicide applications and tilling practices on all plots, there was noticeable increase in perennial weeds commonly found in crop rotation and monoculture systems (Woźniak and Soroka, 2015). Weed distribution could be lower under forage crops because the crop residues tend to suppress new weed emergence (Pittman *et al*., 2020). Crop competitiveness regarding weed control can be assessed by crop tolerance, competitive ability against weeds, or both (Haramoto and Pearce, 2019). The study indicated that all three types of forage crops could grow with immature rubber trees and cover the inter-row areas of rubber trees. This implied that forage crops would play an important role in integrated weed management, especially for controlling broad-leaf and narrow-leaf weed species. However, most native grass, such as whip grass and tropical carpet grass, usually grow well in the areas in the rainy season, but in the dry season, they could cease growing, grow less, or die. Additionally, the efficiency of the weed distribution control of the forage crops varied by season. The ruzi grass could adapt well to the dry season, whereas the whip grass and tropical carpet grass could control the weed distribution significantly in the rainy season. These findings were also reported in previous studies (Yang *et al*., 2010; Yan *et al*., 2014). Environmental conditions such as high temperature and low relative humidity decreased the growth potential of forage crops and subsequent crop yields (Schoofs and Entz, 2000).

3.4 Root Competition between Forage Crops and Rubber Trees

It was observed that all forage crops had higher root length density (RLD) than that of rubber trees in the upper soil layer (0-20 cm) during the whole study period from S_1 (July 2016) to S_3 (March 2017) (Figure 4a-d).



S_1, S_2 and S_3 are the early rainy, heavy rainy and summer seasons, respectively.

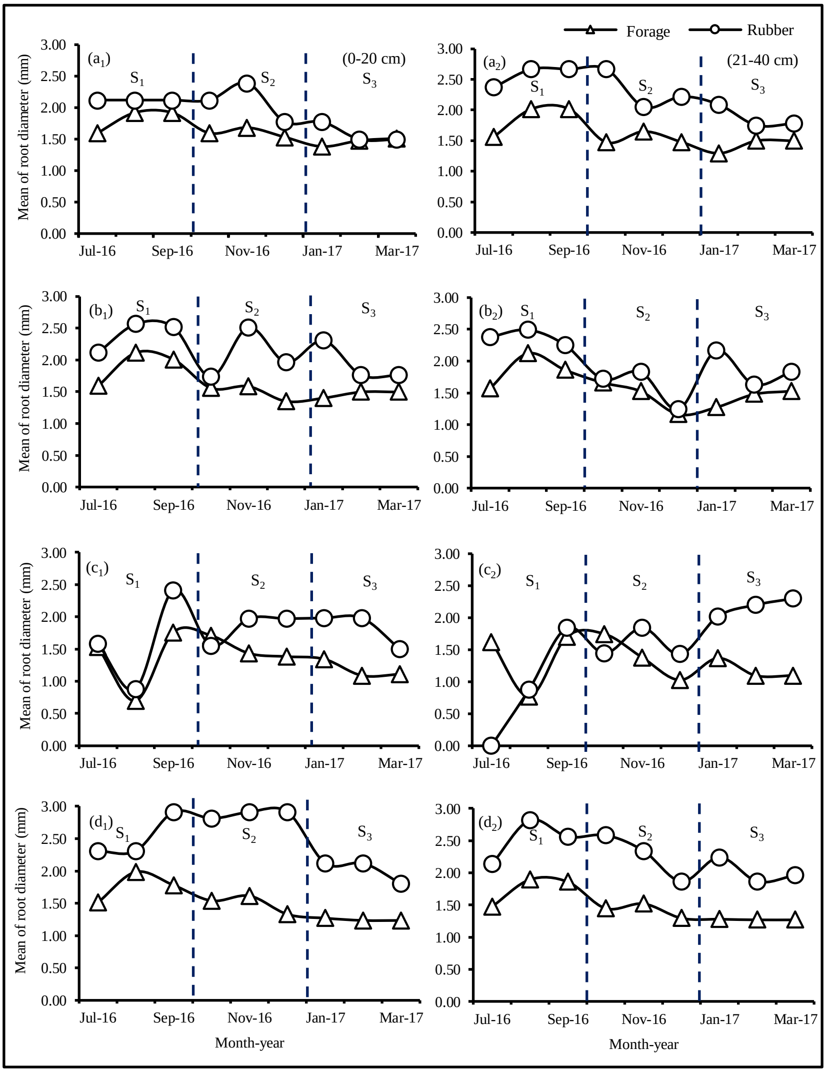
Figure 4. Root length density at 0-20 (a_1-d_1) and 21-40 cm (a_2-d_2) soil depth in natural weeds (a), tropical carpet grass (b), whip grass (c) and ruzi grass (d) in a rubber plantation from July 2016 to March 2017

An overall increase in RLD was found in the soil depth of 0-20 cm from July to November 2016 in S_1 and S_2 seasons. After that, although the RLD sharply decreased until January 2017 (S_3), it increased slightly from January to March 2017. In the S_2 season, the RLDs of the natural weeds and tropical carpet grasses in the 0-20 cm soil depth were 0.60 and 0.32 cm cm^{-2}, respectively, which were higher than that of the rubber trees (Figure 4b_1 and b_2). The greater rubber fine roots were observed in lower soil depth (21-40 cm) in the tropical carpet grass plot in August and October 2016 and February and March 2017. Also, the greatest differences between forage crops and rubber trees in RLD occurred in the ruzi grass plots, as in both soil layers (Figure 4d_1 and d_2).

By considering the root growth and competition between the forage crops and rubber trees, the study uncovered that the roots of both the forage crops and rubber trees were related to each other at a depth of 0-20 cm and 21-40 cm from the soil surface, especially ruzi grass that had a higher competitive ability than rubber tree roots. When compared with weeds or both whip grass and tropical carpet grass, this affected the length of the rubber tree roots less than in the areas of ruzi grass plantations. These displayed a higher relative density and competitive ability of the ruzi grass's root system than other grasses. Meanwhile, the whip grass and tropical carpet grass could spread rapidly from prostrate stolons by nodal root development (Jin *et al.*, 2014) as they had a higher root length density than rubber roots at 0-20 cm soil depth with a slight decrease at 21-40 cm soil depth (Figure 4).

Despite the new root appearance in the rubber trees, there was an overall reduction in RLD in all seasons. In contrast, higher root diameters were observed in rubber trees than those of the forage crops during the study (Figure 5a-d). However, the root diameter of rubber trees dropped in the whip grass plots in October 2016 in both soil layers (Figure 5c_1 and c_2). In the ruzi grass plot, the root diameters of rubber trees were generally similar in both soil layers and about 38.31 and 34.48% longer than those of forage crops in 20- and 40 cm-soil depths, respectively, during the whole study period (Figure 5 d_1 and d_2).

The study detected that the root length growth depended on the soil moisture content, which varied with the rainfall. When soil moisture is less during the summer, forage crops typically generate and expand new roots to a deeper soil layer. Similarly, soil moisture might be influenced by the amount of root density which could conserve water availability in the topsoil layers in a rubber agroforestry system (Saelim *et al.*, 2019). The roots of all forage crops could explore for water and nutrients and respond dynamically to seasonal changes in environmental conditions. Meanwhile, rubber trees might be relied upon to avoid intense competition for surface water as reported in rubber-intercropping systems in the dry period of south-western China (Wu *et al*., 2016).



S_1, S_2 and S_3 are the early rainy, heavy rainy and summer seasons, respectively.

Figure 5. Root diameter at 0-20 (a_1-d_1) and 21-40 cm (a_2-d_2) soil depths in natural weeds (a), tropical carpet grass (b), whip grass (c) and ruzi grass (d) in a rubber plantation from July 2016 to March 2017

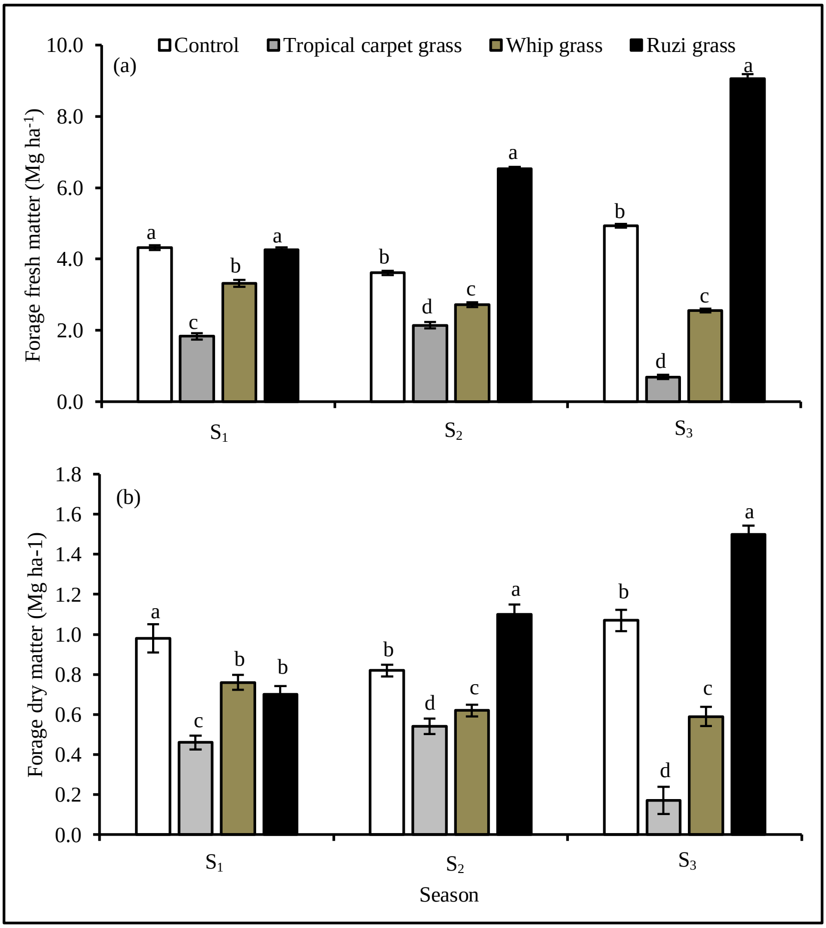
In response to inter-plant root competition, rubber trees likely affected root length density to avoid intense competition for surface root competition. This study found that rubber roots had strong plasticity during root proliferation. Such root growth behavior increased the competition for water availability and nutrients during the development of the rubber root as discussed above; however, root development could be related to the shoot growth potential (Li *et al*., 2006). For the diameter, this study disclosed that the root diameters of all forage crops were smaller than those of the rubber tree, which is a woody plant having fibrous roots (Padovan *et al*., 2015). This might be the reason why the rubber roots were larger than those of the fibrous roots of grasses.

3.5 Forage Yield

The lowest yields of fresh and dry matter were found in the tropical carpet grass, while the highest yields were delivered in the ruzi grass (Figure 6a). Regarding the dry matter, the yield of tropical carpet grass markedly decreased in S_3 after the relatively higher yield of 0.54 Mg ha^{-1} in the heavy rainy season (S_2). Also, there were significant differences in the dry matter of the tropical carpet grass and the whip grass in all seasons. In contrast, the ruzi grass yielded the highest dry matter of 1.50 Mg ha^{-1} in S_3, followed by 0.70 and 1.10 Mg ha^{-1} in S_1 and S_2 periods, respectively (Figure 6b).

This study discovered that the ruzi grass could grow and produce a continuous yield from the rainy seasons (S_1 and S_2) to the summer season (S_3). However, its leaves were folded in the summer season due to high temperature (> 35 °C), low relative humidity (< 40%) and low soil moisture content (5.07-14.35% for all soil depths). Therefore, along with insufficient water management, these might be the key causes why some parts of tropical carpet grass and whip grass stopped growing and died. These arid conditions were likely the major causes that could retard the growth of the tropical carpet grass and whip grass. If there was an insufficient water supply, they could not survive in extreme drought periods. They are a warm-season perennial that is widely grown for summer grazing and hay production, especially whip grass as found in tropical southern Asia and southwestern China (Yang *et al*., 2010) and tropical carpet grass (Uddin *et al*., 2011). Therefore, the three forage types of grass were appropriate for planting in immature rubber plantations.

In comparing the yield productions of the three forage crops, the study unearthed that the ruzi grass was two to four times higher in yield than the whip grass and the tropical carpet grass. Although the control group (natural weeds) could produce high yields after ruzi grass, this was not widely used for feeding animals because natural weeds were unsuitable for livestock. Nevertheless, the nutritional values of forage crops might also depend on other factors such as harvesting age, plant parts and different environments like soil fertility and shade conditions.



S_1, S_2 and S_3 are the early rainy, heavy rainy and summer seasons, respectively. Bars represent the mean, and standard derivation followed by the same letter has no significant difference by DMRT ($p \leq 0.05$).

Figure 6. Seasonal changes in fresh (a) and dry matters (b) of natural weeds, tropical carpet grass, whip grass and ruzi grass in a rubber plantation from July 2016 to March 2017

Despite low yield, the shade-tolerant tropical carpet grass is appropriate for growing under rubber trees older than three years, where light transmission is lesser due to the denser condition of the overstory canopies. However, when rubber plantations are older than three years, row-spaced shrubs would start to become closer to one another resulting in less light transmission (Liu *et al*., 2019). Hence, tropical carpet grass might be an appropriate option because of its suitable self-adaptation under shade conditions despite the lower yields (Wong, 1990; Chanjula *et al*., 2017).

4. Conclusion and Recommendation

The three forage crops exhibited high growth efficiency in an immature rubber plantation. The tropical carpet grass, native forage grasses and whip grass could effectively control the weed distribution in a rubber plantation in all seasons. Likewise, the ruzi grass obtained high efficiency in yield production and good self-adaptation during summer. However, the high root competitiveness of the ruzi grass could affect the growth of rubber tree roots. In addition, the ruzi grass indirectly controlled weed distribution as a biologically and eco-friendly approach in rubber plantations; hence, reducing the use of chemical herbicides. Consequently, utilizing these three types of grass would improve soil fertility, biodiversity and moisture content resulting in beneficial rubber agroecosystems. This would also conform to the relevant policy on reducing or prohibiting some weed killers and could be incorporated into the rubber plantation management guideline in compliance with the Forest Stewardship Council (FSC) standards in the future. However, the cost-effectiveness or benefit-cost ratio associated with the forage crop, growing in immature rubber plantations, and the nutritional values of the forage crops for animals are suggested for further studies. Moreover, annual forage crops may be a valuable part of integrated weed management for reducing the utilization of herbicides with mixed crop-livestock systems in the rubber agroecosystems.

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