



# Cattle grazing impacts on shoot and root characteristics of *Urochloa decumbens* (Stapf) R. Webster and *Axonopus compressus* (Sw.) P. Beauv. in tropical pastures of Malaysia

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## Original Research

Received:  
04 August 2023  
Revised:  
20 January 2024  
Accepted:  
29 January 2024  
Published online:  
20 January 2025

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## Abstract:

This study aimed to assess the responses of Signal grass (*Urochloa decumbens*) and Carpet grass (*Axonopus compressus*) shoot and root systems to cattle grazing. Two sites with different grazing strategies were selected in pastures of Selangor state, Malaysia in 2016: one site was dominated by Signal grass and grazed with moderate intensity for long-term (LMG, 2.7 animal unit/ha/yr) and the second site was dominated by Carpet grass and grazed with heavy intensity for short-term (SHG, 5 animal unit/ha/yr). Shoot growth was similarly assessed for both species by measuring herbage mass, plant height, regrowth rate, tiller density and litter biomass four times at the end of the growing periods in both grazed and ungrazed (control) sites. Root samples of species were taken from the center of the individual plants to a depth of 30 cm and analyzed for root length, diameter, surface area, volume and mass using WinRhizo Root Scanner. The relationship between root distribution parameters and soil depth was examined using least square curve fitting. The LMG strategy increased herbage production (g DM/m<sup>2</sup>), regrowth rate (g DM/d/m<sup>2</sup>) and tiller density of Signal grass by 19, 26 and 69%, respectively, compared with the ungrazed site ( $P < 0.05$ ). For this grazing strategy, the mean root length (-18%) decreased ( $P < 0.05$ ), but root mass (+46%) increased ( $P < 0.05$ ). In SHG strategy, herbage production and regrowth rate of Carpet grass were unaffected by grazing but tiller density was 147% increased than the ungrazed site. This grazing strategy decreased mean root length by 38%, but increased root diameter and volume of Carpet grass by 22 and 59%, respectively, and had no effect on root mass. It was concluded that short-term heavy grazing had negative impacts on the root characteristics of studied species than long-term moderate grazing. Therefore, long-term moderate grazing by cattle is recommended for the study area.

**Keywords:** Herbage mass; Regrowth rate; Tiller density; Root morphology; Root distribution

## Introduction

In Malaysia, grazing lands consist of grazing reserves (communal grazing land) and commercial improved pastures. Grazing reserves are natural grasslands with low productivity and poor forage quality. Carpet grass (*Axonopus compressus*) is a highly dominated species in these ecosystems. These grazing lands are used for communal livestock ranching by smallholders. Heavy stocking rate is a common problem in the majority of natural grassland (Suhartini et

al., 2020). Improved pastures are used for commercial livestock ranching by governmental and private sectors. Despite communal grazing lands, improved pastures are managed intensively with a moderate stocking rate. Signal grass (*Urochloa decumbens*) is one of the introduced grass plant that is largely used to establish improved pastures in Malaysia (Ayorlo, 2010).

Tropical pastures grow for 12 months in a year due to permanent favorable environmental conditions and grass plants complete their growth cycle in 4 to 6 weeks. These pastures

are subject to periodic grazing with varying intensity and frequency (Ayorlo, 2010). Grazing can affect both above- and below-ground phytomass of plants directly or indirectly through defoliation, treading, and waste deposition (Bilotta et al., 2007). Chen et al. (2006) observed that grazing affects the below-ground more than it does the above-ground. However, the response of grass plants to grazing can vary within and between species (Dawson et al., 2000).

The extent of change in pasture plants is greatly influenced by intensity, frequency, timing and period of grazing. In addition, animal species, climatic and edaphic conditions influence the response of pastures to grazing (Deutsch et al., 2010; Sulistijo et al., 2021). Under heavy grazing intensity, for example, herbage production can decrease and the vegetation structure changes to a high density of lower tillers (Dawson et al., 2000). Herbage production, plant height, growth rate, tiller density and litter biomass provide a good set of vegetal indicators for determining the response of shoots to grazing strategy (Holland et al., 2008; Shakhane et al., 2013).

Plant root systems play a pivotal role in the nutrient cycle and energy flow of pasture and grassland ecosystems. It is important to understand the root response to grazing and its importance to pasture health (Peng et al., 2022). Root systems respond to grazing with both architectural and morphological changes, which may affect root demography and/or physiology (Arredondo and Johnson, 1998). Grazing can reduce the rate of root growth (Arredondo and Johnson, 1999) or even result in the complete cessation of root growth and function (Richards, 1984). The reduction in root growth following defoliation is in response to reduced photosynthesis and carbon assimilation, which ensures that leaves can regrow to support the root mass (Hendrickson and Olson, 2006; Ayorlo et al., 2014). The root architecture and morphological response to grazing are also influenced by soil physical and chemical properties, plant physiological condition, and stage of development and carbohydrate allocation patterns (Hendrickson and Olson, 2006).

improved tropical pastures. It is a fast-growing perennial C4 grass that produces both erect shoots and stolons. It has a very dense root system in the upper soil layers with more than 80% of root mass within the first 30 cm of the soil profile (Guenni et al., 2002; Ayorlo, 2010). It has been widely used for the establishment of improved commercial pastures in the tropics. Carpet grass (*Axonopus compressus* (Sw.) P. Beauv.) is a dominant grass in native grasslands of tropical regions. It is a C4 stoloniferous perennial grass that grows in acidic (pH 4.0 – 7.0) and low fertility soils to a maximum height of about 20 – 50 cm (Smith and Valenzuela, 2002; Ayorlo, 2010). Both species are dependent on grazing disturbance, or anthropogenic interference, for their maintenance.

Grazing affects below-ground parts of plants more than it does above-ground processes (Chen et al., 2006). Although knowledge of plant root characteristics is essential to understanding pasture healthiness and plant uptake of soil water and nutrients in grassland, most published literature has reported the response of plants above-ground parts to animal grazing and few of such studies have been

conducted to quantify root responses to grazing (Ayorlo, 2010). One of the reasons behind this is that the study of root distribution is tedious and time-consuming. Therefore, the root system of the grassland ecosystem is one of the least studied components. It is estimated that less than 10% of the studies on pastures and rangeland have evaluated the below-ground biomass production (Oliveria et al., 2000). There is a general agreement among scientists about the importance of both shoot and root studies when evaluating the effect of defoliation on grasses (for example, (Greenwood and Hutchinson, 1998; Dawson et al., 2000; Mousel et al., 2004; Chen et al., 2006; Lodge and Murphy, 2006; Wang et al., 2023)). However, most published studies report only on the above-ground response and studies that examine both above- and below-ground response are limited (Greenwood and Hutchinson, 1998; Dawson et al., 2000; Oliveria et al., 2000; Chen et al., 2006). Our study is probably among the first studies that quantified the influence of grazing management strategies on the distribution and morphology of roots in tropical pastures of Malaysia. Therefore, we conducted a study to quantify the responses of both shoot growth and root morphology and the distribution characteristics of Signal grass and Carpet grass to long-term moderate and short-term heavy grazing strategies in tropical pastures with the ultimate goal of understanding the effect of grazing on the health of these grasslands. In this study, we tested the hypothesis that moderated grazing would improve pasture plants' shoots and roots, whereas heavy grazing would impair them.

## Materials and Method

### Site information

This study was conducted in two experimental sites at the University Putra Malaysia Livestock Section (2°58' North and 101°43' East), about 20 km south of Kuala Lumpur, Selangor state, Malaysia. Two sites with different grazing strategies were selected: the first one was dominated largely by *U. decumbens* and grazed with moderate intensity for long-term (LMG) and the second was mainly dominated by *A. compressus* and grazed with heavy intensity for short-term (SHG). A grazing enclosure was also constructed contiguous to the grazed site on terrain with similar topography, soils and vegetation. The enclosure provided a control to compare the grazing effects. The area has a humid tropical climate with a mean annual rainfall of 2,471 mm and a mean annual temperature of 24.5°C. The soil type was classified as Typic Hapludox (Munchong series) according to USDA classification; representing the Oxisols order with > 35% clay at the study sites. The soils of the sites were generally well-drained.

### Research method

One site has been grazed with 2.7 animal units (AUs)/ha/year (long-term grazing, LMG) and another site has been grazed with 5 AUs/ha/year (short-term grazing, SHG) for 2 years. Therefore, in Signal grass pasture the treatments were no grazing and cattle grazing at a moderate stocking density under a rotational grazing system, and at Carpet grass pasture the treatments were no grazing and

cattle grazing at a heavy stocking density under a rotational grazing system.

### Shoot measurements

A set of four, 10-m equally-spaced transects were established spaced 100 m apart in each plot at the LMG site. Furthermore, two 10-m transects spaced 20 m apart were established in each plot at the SHG site. Length and the number of transects were determined according to canopy cover percent, plant density and distribution pattern (Gillison, 2006). An enclosure cage technique was used to protect pasture plants from grazing treatments (Mannetje, 1978). For this purpose, one quadrat (0.25 m<sup>2</sup>) with an enclosure cage was randomly placed in each transect.

Immediately after cattle removal from the paddocks, residual ungrazed vegetation of an area of the same size to quadrat was clipped at ground level (Martinez and Zinck, 2004) and the grass plants were allowed to grow undisturbed under the protection cages for six or eight weeks in SHG and LMG pasture sites, respectively. After completion of plants growth under the cages, we measured the average tiller height using a pasture ruler (MLA, Australia) and counted tiller numbers. Standing and fallen plant materials that have been senesced in the current growing period were collected as litter biomass. Plant materials that were produced in the current growing period and have been senesced were considered litter in this study. All biomass was oven-dried and weighed. Pasture regrowth rate was expressed as the change in live biomass (DM) per unit of time (g DM/m/day) and calculated using equation 1 (Bluett et al., 1998).

$$\text{Regrowth rate} = \frac{\Delta y_f}{\Delta t} \quad (1)$$

where;  $\Delta y_f$  is dry matter biomass (g DM m<sup>-2</sup> day<sup>-1</sup>) after regrowth, and  $\Delta t$  is the number of days between harvests. Both sites were sampled four times every six weeks on the SHG site and eight weeks intervals at the LMG site. These frequencies were defined by the growth cycle of tropical grass plants, which is longer for introduced tropical species than native grass species. All transects and enclosure cages were moved to new locations and reestablished randomly after each sampling event.

### Root measurements

Roots were sampled by extracting soil cores, directly in the center of the plants, using a manually driven single root auger (Eijkelpamp Agrisearch Equipment) with an 8-cm diameter bore to a depth of 30 cm (Oliveria et al., 2000; Mousel et al., 2005). Soil cores were randomly extracted from each quadrat, and were cut into three, 10-cm segments. Individual segments of root samples were gently hand-washed with tap water to remove soil materials over a 0.20 mm sieve to ensure that fine roots were retained (Matthew et al., 1991; Lodge and Murphy, 2006).

Root samples were then placed on the tray of a root scanner (WinRhizo, Regent Instruments Inc., Quebec, Canada) containing distilled water to a depth of 3 cm. A digitized image of the entire root system of each segment was obtained with a resolution of 400 dots per inch (dpi). Each image

was analyzed for root length (cm), surface area (cm<sup>2</sup>), average diameter (mm) and volume (cm<sup>3</sup>). Finally, roots were oven-dried at 65 °C to determine mass (Mousel et al., 2005). Root length density (RLD), specific root length (SRL), root mass density (RMD), surface area density (SAD), and root volume density (RVD) were calculated for each 10-cm soil core segment.

### Data analysis

Site differences were expected due to differences in their grazing strategies, pasture type, and treatment period. Thus, pasture sites were evaluated separately. Grazing intensity was considered as a fixed effect (first factor). The effects of treatments on root variables were analyzed across soil depth intervals (second factor), which were treated as a repeated measure in space.

Assumptions of normality and homogeneity of variance were checked and variables with non-normal distribution were log-transformed as appropriate. For log-transformed variables, the mean of the untransformed data was used to express central tendency, and the standard error derived from log-transformed data was used to express precision. All variables of shoot characteristics in each site were averaged for four sampling events to produce a single estimate and eliminate that factor from statistical analyses. Multi-variate analysis of variance (MANOVA) using the general linear model (GLM) procedure was applied to analyze shoot data. Root data was analyzed with repeated measure analysis of variance (RM-ANOVA) in SPSS software (IBM SPSS Statistics, Version 25.0). Differences were assessed at the significance level of  $P < 0.05$ .

The relationship between root distribution parameters as dependent variable (Y) and root characteristics including root length density, root surface area density, root volume density and root mass density with soil depth as independent variables (X) for individual cores were examined by least square curve fitting. Five curvilinear functions, i.e., linear, logarithmic, power and exponential were compared.

## Results

### Shoot growth

#### *Long-term moderate grazing (LMG):*

Herbage production (g DM/m<sup>2</sup>) was positively affected ( $P \leq 0.05$ ) by long-term moderate grazing (LMG). Mean pasture height (cm) was not affected by this grazing treatment. The regrowth rate was affected ( $P < 0.05$ ) by the LMG treatment. Reproductive and vegetative tiller densities (tillers/m<sup>2</sup>) were significantly higher ( $P < 0.05$ ) in grazed pasture than in grazing enclosure. The LMG treatments caused a significant decrease ( $P < 0.05$ ) in the litter biomass of Signal grass (Table 1).

#### *Short-term heavy grazing (SHG):*

Herbage production (g DM/m<sup>2</sup>) of Carpet grass was unaffected by short-term heavy grazing (SHG). Mean pasture height (cm) and the regrowth rate were not affected by SHG treatment. Reproductive and vegetative tiller densities (tillers/m<sup>2</sup>) were significantly higher than enclosure

**Table 1.** Means of shoot growth parameters of the studied grass species under two cattle grazing managements in tropical pastures of Malaysia.

| Species      | Grazing treatments | Herbage production (g DM/m <sup>2</sup> ) | Pasture height (cm) | Regrowth rate (g DM/m <sup>2</sup> /d) | Reproductive tiller (tillers/m <sup>2</sup> ) | Vegetative tiller (tillers/m <sup>2</sup> ) | Tiller density (tiller/m <sup>2</sup> ) | Litter biomass (g/m <sup>2</sup> ) |
|--------------|--------------------|-------------------------------------------|---------------------|----------------------------------------|-----------------------------------------------|---------------------------------------------|-----------------------------------------|------------------------------------|
| Signal grass | LMG                | 160.23a                                   | 35.41a              | 3.23a                                  | 3.98a                                         | 12.30a                                      | 70.93a                                  | 10.99a                             |
|              | Exclosure          | 132.35b                                   | 34.84a              | 2.47b                                  | 2.48b                                         | 6.12b                                       | 34.56b                                  | 22.65b                             |
|              | <i>F</i>           | 2.10                                      | 0.024               | 5.81                                   | 9.42                                          | 10.35                                       | 11.85                                   | 3.81                               |
|              | <i>P</i> -value    | 0.05                                      | 0.2                 | 0.02                                   | 0.003                                         | 0.002                                       | 0.001                                   | 0.046                              |
| Carpet grass | SHG                | 134.70a                                   | 14.11a              | 2.58a                                  | 75.13a                                        | 21.45a                                      | 386.64a                                 | 10.97a                             |
|              | Exclosure          | 129.88a                                   | 16.50a              | 2.41a                                  | 5.18b                                         | 9.25b                                       | 57.79b                                  | 17.75b                             |
|              | <i>F</i>           | 0.074                                     | 2.24                | 0.025                                  | 56.58                                         | 16.01                                       | 49.36                                   | 3.95                               |
|              | <i>P</i> -value    | 0.78                                      | 0.14                | 0.61                                   | 0.00                                          | 0.00                                        | 0.00                                    | 0.048                              |

LMG: long-term moderate grazing; SHG: Short-term heavy grazing  
Means within a column with the same letter are not significantly different at  $P < 0.05$ .

( $P < 0.05$ ). The SHG treatments caused a significant decrease ( $P < 0.05$ ) in the litter biomass of Carpet grass plants (Table 1).

### Root characteristics

#### Long-term moderate grazing (LMG):

**a) Signal grass:** There were significant differences between moderate grazing and grazing exclosure (control) for root length, root length density, specific root length, root mass and root mass density ( $P < 0.05$ ). The lower values of root length, root length density, specific root length, and the higher values of root biomass and root mass density were obtained in moderately grazed site than in the exclosure ( $P \leq 0.05$ ) (Table 2).

There were significant differences between soil depths for all root traits, except for specific root length ( $P < 0.05$ ). The higher and lower values of all the traits were obtained in 0 – 10 and 20 – 30 cm soil depths, respectively (Table 2). The moderate grazing by soil depth interaction effect was only significant for specific root length ( $P < 0.05$ ), indicating that root characteristics of Signal grass in moderately grazed and exclosure sites had similar responses in various soil depths (Table 3).

The mean root length of grazed Signal grass was 18% lower ( $P < 0.05$ ) than that in the ungrazed pasture. The mean root diameter of grazed Signal grass was 12% higher ( $P < 0.05$ )

than that in the ungrazed pasture. The mean root mass of Signal grass in LMG pasture was 46.5% higher than that for the ungrazed pasture of Signal grass. Grazed plants of Signal grass had 92% less specific root length in LMG pasture. Overall, moderate grazing had no significant negative impact on the root traits of Signal grass over time.

#### Short-term heavy grazing (SHG):

**b) Carpet grass:** There were significant differences between heavy grazing and grazing exclosure (control) for root length, root diameter, root volume, RLD, SRL and RVD ( $P < 0.05$ ). Short-term heavy grazing (SHG) strategy resulted significantly lower root length, RLD, and SRL, but significantly higher root diameter, root volume and RVD in Carpet grass in comparison with ungrazed site ( $P < 0.05$ ) (Table 4).

There were significant differences between consecutive soil depths with regard to root length, root mass, RLD and RMD of Carpet grass ( $P < 0.05$ ). The higher and lower values of all these traits were obtained in 0 – 10 and 20 – 30 cm soil depths, respectively. However, root diameter, root surface area, root volume, SAD and RVD of Signal grass were significantly varied only between 0 – 10 and 10 – 20 cm soil depths ( $P < 0.05$ ) (Table 4).

The interaction of grazing treatment by soil depth effects was not significant for root length, root diameter, root mass,

**Table 2.** Responses of root morphological and distribution variables of Signal grass (*Urochloa decumbens*) in different soil depths to long-term moderate cattle grazing (LMG) in tropical pastures of Malaysia.

| Variable        | Length (cm) | Diameter (mm) | Surface area (cm <sup>2</sup> ) | Volume (cm <sup>3</sup> ) | Mass (mg) | RLD (cm/cm <sup>3</sup> ) | SRL (cm/mg) | RMD (mg/cm <sup>3</sup> ) | SAD (cm <sup>2</sup> /cm <sup>3</sup> ) | RVD (cm <sup>3</sup> /cm <sup>3</sup> ) |
|-----------------|-------------|---------------|---------------------------------|---------------------------|-----------|---------------------------|-------------|---------------------------|-----------------------------------------|-----------------------------------------|
| Treatment       |             |               |                                 |                           |           |                           |             |                           |                                         |                                         |
| LMG             | 1064.3b     | 0.79a         | 264.14a                         | 8.91a                     | 946.6a    | 2.12b                     | 1.36b       | 1.89a                     | 0.53a                                   | 0.018a                                  |
| Exclosure       | 1275.5a     | 0.70a         | 210.97a                         | 7.40a                     | 589.8b    | 2.55a                     | 3.68a       | 1.17b                     | 0.42a                                   | 0.014a                                  |
| <i>F</i>        | 4.12        | 0.23          | 2.11                            | 0.25                      | 15.71     | 4.12                      | 39.16       | 12.91                     | 2.11                                    | 0.247                                   |
| <i>P</i> -value | 0.05        | 0.63          | 0.16                            | 0.62                      | 0.001     | 0.05                      | 0.00        | 0.002                     | 0.162                                   | 0.625                                   |
| Soil Depth      |             |               |                                 |                           |           |                           |             |                           |                                         |                                         |
| 0 – 10 cm       | 2104.69a    | 1.43 a        | 580.37a                         | 22.30a                    | 1595.3a   | 4.28a                     | 1.95ba      | 3.39a                     | 1.15a                                   | 0.045a                                  |
| 10 – 20 cm      | 948.91b     | 0.42b         | 81.41b                          | 1.62b                     | 573.06b   | 2.19b                     | 2.15a       | 1.14b                     | 0.16b                                   | 0.003b                                  |
| 20 – 30 cm      | 406.33c     | 0.39b         | 50.90c                          | 0.54c                     | 136.40c   | 0.80 c                    | 3.46b       | 0.38c                     | 0.10c                                   | 0.001c                                  |
| <i>F</i>        | 2.90.76     | 12.34         | 132.00                          | 17.64                     | 103.67    | 290.76                    | 8.54        | 42.31                     | 131.99                                  | 17.64                                   |
| <i>P</i> -value | 0.00        | 0.002         | 0.00                            | 0.00                      | 0.00      | 0.00                      | 0.004       | 0.00                      | 0.00                                    | 0.00                                    |

Means within a column with the same letter are not significantly different at  $P < 0.05$ .

LMG = long-term moderate grazing; RLD: root length density, SRL: specific root length, RMD: root mass density, RSAD: surface area density, RVD: root volume density.



**Table 3.** Means of root traits of Signal grass (*Urochloa decumbens*) in response to long-term moderate grazing (LMG) by cattle grazing and enclosure in different soil depths.

| Grazing treatment | Depth (cm) | Length (cm) | Diameter (mm) | Volume (cm <sup>3</sup> ) | Mass (mg) | SA (cm <sup>2</sup> ) | RLD                | SRL    | RMD  | SAD  | RVD    |
|-------------------|------------|-------------|---------------|---------------------------|-----------|-----------------------|--------------------|--------|------|------|--------|
|                   |            |             |               |                           |           |                       | mg/cm <sup>3</sup> |        |      |      |        |
| LMG               | 0 – 10     | 1939.3a     | 1.39          | 24.14                     | 1971.6    | 609.51                | 3.85               | 1.09 e | 4.37 | 1.21 | 0.048  |
|                   | 10 – 20    | 770.7 b     | 0.51          | 1.85                      | 685.8     | 123.82                | 1.53               | 1.80 c | 1.36 | 0.24 | 0.0037 |
|                   | 20 – 30    | 383.0 b     | 0.50          | 0.75                      | 182.5     | 59.11                 | 0.76               | 1.29 d | 0.58 | 0.11 | 0.0014 |
| Exclosure         | 0 – 10     | 2270.0a     | 1.48          | 20.47                     | 1219.0    | 551.22                | 4.72               | 2.81 b | 2.42 | 1.09 | 0.048  |
|                   | 10 – 20    | 1127.1b     | 0.33          | 1.39                      | 460.30    | 99.01                 | 2.85               | 2.50 b | 0.91 | 0.08 | 0.0044 |
|                   | 20 – 30    | 429.5 b     | 0.28          | 0.35                      | 90.30     | 42.69                 | 0.84               | 5.74 a | 0.18 | 0.08 | 0.0006 |
| <i>F</i>          |            | 2.85        | 0.23          | 0.14                      | 5.64      | 0.43                  | 2.85               | 12.63  | 3.29 | 0.43 | 0.14   |
| <i>P</i> -value   |            | 0.05        | 0.71          | 0.71                      | 0.07      | 0.53                  | 0.06               | 0.00   | 0.07 | 0.53 | 0.71   |

Means within a column with the same letter are not significantly different at  $P < 0.05$ .

SA= Surface area, RLD: root length density, SRL: specific root length, RMD: root mass density,

RSAD: surface area density, RVD: root volume density.

**Table 4.** Response of root morphological and distribution variables of Carpet grass (*Axonopus compressus*) in different soil depths to short-term heavy (SHG) cattle grazing in tropical pastures of Malaysia.

| treatment       | Depth (cm) | Length (cm) | Diameter (mm) | Volume (cm <sup>3</sup> ) | Mass (mg) | SA (cm <sup>2</sup> ) | RLD                | SRL    | RMD  | SAD  | RVD    |
|-----------------|------------|-------------|---------------|---------------------------|-----------|-----------------------|--------------------|--------|------|------|--------|
|                 |            |             |               |                           |           |                       | mg/cm <sup>3</sup> |        |      |      |        |
| SHG             | 0 – 10     | 1939.3a     | 1.39          | 24.14                     | 1971.6    | 609.51                | 3.85               | 1.09 e | 4.37 | 1.21 | 0.048  |
|                 | 10 – 20    | 770.7 b     | 0.51          | 1.85                      | 685.8     | 123.82                | 1.53               | 1.80 c | 1.36 | 0.24 | 0.0037 |
|                 | 20 – 30    | 383.0 b     | 0.50          | 0.75                      | 182.5     | 59.11                 | 0.76               | 1.29 d | 0.58 | 0.11 | 0.0014 |
| Exclosure       | 0 – 10     | 2270.0a     | 1.48          | 20.47                     | 1219.0    | 551.22                | 4.72               | 2.81 b | 2.42 | 1.09 | 0.048  |
|                 | 10 – 20    | 1127.1b     | 0.33          | 1.39                      | 460.30    | 99.01                 | 2.85               | 2.50 b | 0.91 | 0.08 | 0.0044 |
|                 | 20 – 30    | 429.5 b     | 0.28          | 0.35                      | 90.30     | 42.69                 | 0.84               | 5.74 a | 0.18 | 0.08 | 0.0006 |
| <i>F</i>        |            | 2.85        | 0.23          | 0.14                      | 5.64      | 0.43                  | 2.85               | 12.63  | 3.29 | 0.43 | 0.14   |
| <i>P</i> -value |            | 0.05        | 0.71          | 0.71                      | 0.07      | 0.53                  | 0.06               | 0.00   | 0.07 | 0.53 | 0.71   |

Means within a column with the same letter are not significantly different at  $P < 0.05$ .

SA= Surface area, RLD: root length density, SRL: specific root length, RMD: root mass density,

RSAD: surface area density, RVD: root volume density.

and RLD, SRL and RMD of Carpet grass. However, root surface area, root volume, SAD and RVD were significantly affected by the interaction of grazing and soil depths ( $P < 0.05$ ) (Table 5), indicating that these characteristics of Carpet grass in heavily grazed and exclosure sites had different responses in various soil depths.

The mean root length of grazed Carpet grass was 38% lower ( $P < 0.05$ ) than that in the ungrazed pasture. The mean root diameter of grazed Carpet grass was 22% higher ( $P < 0.05$ ) than that in the ungrazed pasture. The mean root volume was 59% higher ( $P < 0.05$ ) in heavily grazed Carpet grass compared to its grazing exclosure. Grazed plants of Carpet

grass had 57% lower specific root length in SHG pasture. Overall, heavy grazing affected roots adversely in Carpet grass.

### Relationships between root traits and soil depths

**a) Signal grass:** The exponential and logarithmic functions with similar  $R^2 = 0.72$  were the best functions in the description of root length density and soil depth for Signal grass. The relationships between root surface area and volume densities with soil depths were best explained by power and exponential functions. Similar  $R^2$  values of 0.82 and 0.81 were explored for both surface and volume densities,

**Table 5.** Means of root traits of Carpet grass (*Axonopus compressus*) in response to short-term heavy cattle grazing (SHG) and grazing exclosure in different soil depths.

| Grazing treatment | Depth cm | Length (cm) | Diameter (mm) | Volume (cm <sup>3</sup> ) | Mass (mg) | SA (cm <sup>2</sup> ) | RLD                   | SRL  | RMD  | SAD   | RVD     |
|-------------------|----------|-------------|---------------|---------------------------|-----------|-----------------------|-----------------------|------|------|-------|---------|
|                   |          |             |               |                           |           |                       | (mg/cm <sup>3</sup> ) |      |      |       |         |
| SHG               | 0 – 10   | 2717.40     | 0.46          | 7.16 a                    | 1692.50   | 489.0 a               | 5.40                  | 1.96 | 3.36 | 0.97a | 0.0140a |
|                   | 10 – 20  | 251.57      | 0.32          | 0.20 c                    | 245.00    | 25.30 b               | 0.50                  | 2.43 | 0.48 | 0.05b | 0.0004b |
|                   | 20 – 30  | 61.31       | 0.27          | 0.05 c                    | 54.00     | 5.37 b                | 0.18                  | 4.60 | 0.10 | 0.02b | 0.0001b |
| Exclosure         | 0 – 10   | 2957.21     | 0.30          | 3.07 b                    | 1120.00   | 326.6 a               | 5.88                  | 3.11 | 2.22 | 0.65a | 0.0060a |
|                   | 10 – 20  | 1079.08     | 0.26          | 0.50 c                    | 229.14    | 71.92 b               | 2.14                  | 5.75 | 0.45 | 0.14b | 0.0010b |
|                   | 20 – 30  | 418.48      | 0.29          | 0.44 c                    | 94.57     | 37.08 b               | 1.38                  | 7.37 | 0.18 | 0.12b | 0.0008b |
| <i>F</i>          |          | 1.16        | 4.00          | 16.79                     | 3.03      | 9.90                  | 0.91                  | 0.83 | 3.03 | 10.34 | 16.79   |
| <i>P</i> -value   |          | 0.307       | 0.26          | 0.001                     | 0.09      | 0.004                 | 0.37                  | 0.41 | 0.09 | 0.004 | 0.001   |

Means within a column with the same letter are not significantly different at  $P < 0.05$ .

RLD: root length density, SRL: specific root length, RMD: root mass density,

SAD: surface area density, RVD: root volume density.

respectively. Root mass density and soil depth relationship was best depicted by the exponential ( $R^2 = 0.81$ ) function (Table 6).

**b) Carpet grass:** The relationships between root length and volume densities with soil depths based on individual root cores of Carpet grass were best depicted by, exponential followed by power functions. The coefficients of determination ( $R^2$ ) for root length and root volume densities were 0.58 and 0.64 for the exponential function and 0.58 and 0.69 for power function, respectively. Root surface area density and soil depth relationship was best described by power ( $R^2$

= 0.81) and logarithmic ( $R^2 = 0.80$ ) functions. The highest  $R^2$  value for the relationship between root mass density and soil depth was signalized by power function ( $R^2 = 0.70$ ). The linear function was the poor predictor of the relationship between measured root distribution characteristics of Carpet grass with soil depth among the functions (Table 7).

**Table 6.** Relationships between root characteristics as dependent variables (Y) and soil depth (cm) as independent variables (X) for individual root samples of Signal grass (*Urochloa decumbens*) under long-term moderate grazing.

| Function    | Equation           | Root traits | Unit                             | a      | b      | ( $R^2$ )* |
|-------------|--------------------|-------------|----------------------------------|--------|--------|------------|
| Linear      | $Y = a - bX$       | RLD         | cm/cm <sup>3</sup>               | 5.54   | -1.162 | 0.71       |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 1.622  | -0.555 | 0.68       |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.003  | -0.001 | 0.68       |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 4.629  | -1.544 | 0.65       |
| Exponential | $Y = ae^{-bX}$     | RLD         | cm/cm <sup>3</sup>               | 9.394  | -0.850 | 0.72       |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 3.856  | -1.313 | 0.81       |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.008  | -1.313 | 0.81       |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 12.947 | -1.384 | 0.75       |
| Power       | $Y = aX^{-b}$      | RLD         | cm/cm <sup>3</sup>               | 4.190  | -1.484 | 0.69       |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 1.143  | -2.350 | 0.82       |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.002  | -2.350 | 0.82       |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 3.447  | -2.402 | 0.71       |
| Logarithmic | $Y = a - b \log X$ | RLD         | cm/cm <sup>3</sup>               | 4.043  | -2.928 | 0.72       |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 1.132  | -1.036 | 0.75       |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.002  | -0.002 | 0.75       |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 3.229  | -2.816 | 0.68       |

RLD: root length density, RMD: root mass density, RSAD: surface area density, RVD: root volume density.

**Table 7.** Relationships between root characteristics as dependent variables (Y) and soil depth (cm) as independent variables (X) for individual root samples of Carpet grass (*Axonopus compressus*) under short-term heavy grazing.

| Function    | Equation           | Root traits | Unit                             | a     | b      | $R^2$ |
|-------------|--------------------|-------------|----------------------------------|-------|--------|-------|
| Linear      | $Y = a - bX$       | RLD         | cm/cm <sup>3</sup>               | 5.27  | -1.753 | 0.43  |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 1.22  | -0.448 | 0.70  |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.013 | -0.005 | 0.47  |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 3.343 | -1.206 | 0.58  |
| Exponential | $Y = ae^{-bX}$     | RLD         | cm/cm <sup>3</sup>               | 9.00  | -1.102 | 0.58  |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 3.688 | -1.715 | 0.75  |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.034 | -1.771 | 0.64  |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 9.340 | -1.629 | 0.67  |
| Power       | $Y = aX^{-b}$      | RLD         | cm/cm <sup>3</sup>               | 3.25  | -1.965 | 0.58  |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 0.790 | -3.153 | 0.81  |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.007 | -3.250 | 0.69  |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 2.107 | -2.932 | 0.70  |
| Logarithmic | $Y = a - b \log X$ | RLD         | cm/cm <sup>3</sup>               | 3.72  | -3.261 | 0.48  |
|             |                    | RSAD        | cm <sup>2</sup> /cm <sup>3</sup> | 0.832 | -0.847 | 0.80  |
|             |                    | RVD         | cm <sup>3</sup> /cm <sup>3</sup> | 0.009 | -0.009 | 0.55  |
|             |                    | RMD         | mg/cm <sup>3</sup>               | 2.292 | -2.264 | 0.66  |

RLD: root length density, RMD: root mass density, RSAD: surface area density, RVD: root volume density.

## Discussion

### Shoot growth

We found no evidence that moderate and heavy rotational grazing impaired the health of Signal grass (*Urochloa decumbens*) and Carpet grass (*Axonopus compressus*), respectively, grown in the humid tropics of Malaysia. On the contrary, grazing enhances forage production of Signal grass and the regrowth potential of both species by producing higher tiller and root mass. This response appears to be related to defoliation by grazing that promotes overcompensation through the increase in tillering and regrowth rate and the reduction of litter by trampling or grazing that releases shading.

The increase in herbage production in grazed site improved pasture of Signal grass may be associated with improved plant nutrient uptake in such pastures as soil readily available nutrients increase in pastures with grazing (Risser and Parton, 1982; Wang et al., 2023). Consistent with our findings of no significant negative impact of SHG on herbage production in Carpet grass, Li et al. (2009) found higher herbage production in pastures with heavy and moderate grazing intensities of rough fescue (*Festuca campestris*) grassland in Canada. No negative impact of SHG on herbage production can be explained by compensation for tissue removal by plants (Langlands and Bennett, 1973) which an increase in herbage mass occurs when overcompensation happens (Li et al., 2009). Regrowth is defined as the increase in size, volume and mass of a plant as a function of time (Pinto et al., 2004). An increase in the regrowth rate of Signal grass under long-term moderate grazing can be primarily ascribed to a higher rate of biomass recovery and stimulation of plants by animal biting to compensate for removed tissues (Sulistijo et al., 2021). Moreover, the high regrowth potential of grass under grazing may be attributable to the adaptation of such grasses to grazing over time. Shelton and Wilson (1990) stated that *Axonopus compressus*, the dominant grass species in the native tropical pastures, is renowned for its ability to endure heavy grazing intensity.

Tiller density is the most important parameter of pasture structure and dynamics (Sabrissia et al., 2004). Pastures under cattle grazing had greater reproductive and vegetative tiller densities in this study (Table 1). The large number of tillers accelerates refoliation and herbage production accordingly (Hoglund et al., 2005). Higher tiller density in grazed pastures is likely related to higher soil nutrient levels. A moderate amount of accumulated litter, a higher rate of compensation of tissue removal in such pastures. Tillers were denser and shorter in grazed pastures, particularly in heavily grazed native pastures of Carpet grass (Table 1). The high density and small size of tillers can be directly attributable to above-ground morphological adaptation to herbivory grazing pressure (Dawson et al., 2000). Moreover, both grasses are rhizomatous and that grazing enhanced tillering. Individual tillers are usually associated with roots at their node with the rhizome/stolon, and therefore explaining the higher mass and, perhaps, the shorter root length.

Our result on litter biomass is in agreement with the findings of Donkor et al. (2001) and Xie and Wittig (2004) that

litter biomass production decreased in pastures with grazing. Higher litter production in grazing enclosure can be ascribed to soil nutrient levels. As in pastures with live-stock grazing, the available form of nutrients for plants is higher than in pastures without livestock. Thus, there is a sufficient supply of nutrients for plant uptake in grazed pastures (Deutsch et al., 2010). This causes a delay in leaf and shoots senescence, which may happen faster in insufficient soil nutrients and competitive environments. High senescence rates increase litter production (Li et al., 2009).

### Root characteristics

Early studies of plant roots under pasture were usually limited to root mass data (Greenwood and Hutchinson, 1998). Measurement of root mass does not facilitate the interpretation of root function and may bias the interpretation of treatment (Noordwijk, 1993). Image analysis techniques have now become available that enable to estimate root length, diameter, surface area, etc. Accurate estimation of these parameters can provide valuable data for understanding the root functions. In this study, root morphological traits including root length, diameter, surface area, and volume were estimated using modern techniques to compute root distribution characteristics and to quantify root response to grazing management strategies.

Root diameter, volume and surface area of Carpet grass were lower compared with Signal grass. Differences in measured root parameters of both species may be related to the different grass species in these areas. Grass plants of the native pasture mainly consist of native perennials with finer roots. Different species utilize various strategies with respect to root traits to cope with grazing may be important mechanisms that allow grassland plants to persist in spatially and temporally heterogeneous environments (Ayorlo et al., 2014). The results of this study thus implicate the plasticity of structural traits as a major determinant of the species-specific responses of environmental variation. The response of root morphological traits to grazing may also be contingent on other environmental conditions, i.e., grazing severity, frequency, timing, soil moisture, soil compaction, and soil type. Consequently, responses to grazing may differ among species and need to be investigated more.

We observed no evidence that moderate or heavy rotational grazing in a humid tropical grassland community of Signal grass and Carpet grass impaired root development that was detrimental to their health. On the contrary, root mass, surface area and most concomitant variables associated with them were either higher with grazing or unaffected by it. This response would seem reasonable as the roots and above-ground portion of the plant are interdependent and further supports the conclusion that rotational grazing benefits these grasslands. However, of the root variables measured, only length was reduced by grazing in both grasses. Observation from other well-documented cases where judicious disturbance either from grazing or fire was essential in maintaining grasslands supports this finding (Oliveria et al., 2004; Mousel et al., 2005; Shakhane et al., 2013).

Longer roots are important as available nutrients become more limiting and competition for them becomes more se-

vere (Chen et al., 2006). In contrast, grazed pastures contain higher levels of nutrients due to a more rapid turnover of nutrients through cattle excreta and trampling (Peng et al., 2022). Consequently, root elongation and proliferation in pastures with animal grazing are lower due to the availability of sufficient nutrients in the soil (McInenly et al., 2009; Ayorlo, 2010). While grazing reduced root length for Signal grass and Carpet grass and their root length densities were well within the range proposed by Noordwijk (1993) for uptake of needed water and phosphorus.

Root surface area is an important factor for the absorption of relatively immobile nutrients and has a significant role across the soil-root interface (Greenwood and Hutchinson, 1998; Peng et al., 2022). The number of grazing events and the length of recovery intervals between the grazing were reported as principal factors influencing root surface area (Mousel et al., 2005). Similar to our study, Greenwood and Hutchinson (1998) report that surface area density was generally similar between grazed and ungrazed treatments in temperate pastures grazed at low and high stocking rates for 30 years in New South Wales. Higher length and diameter of roots over soil depth resulted in markedly higher root surface area densities. The correlation coefficient ( $r$ ) of root surface area density with length and diameter were 0.80 and 0.79 in our study, respectively.

Root volume of Signal grass and Carpet grass was highly correlated with root diameter rather than root length. Correlation coefficients of Signal grass root volume with length and diameter were 51 and 95%, respectively, and 74 and 77% for Carpet grass. Root volume is a function of root length and diameter. Engel et al. (1998) indicated that root length probably is the principal factor affecting root volume of grasses. Conversely, Mousel et al. (2005) observed that root diameter rather than root length was the key variable influencing root volume of big bluestem (*Andropogon gerardii*).

Our observation that grazed grasses had higher total root mass than ungrazed grasses is supported by Milchunas and Lauenroth (1993). In contrast, Dawson et al. (2000) and Oliveria et al. (2004) reported that the root mass in grazed pastures was lower than in ungrazed pastures. High root mass grazed pastures can be attributable to the absence of cultivation practices in the in pastures and the presence of an unknown proportion of dead and non-functional roots in samples. Since cattle grazing accelerates root death by treading and defoliation, high amounts of dead material can be expected in root samples from grazed pastures (Ayorlo et al., 2014). Additionally, a high proportion of fine roots was visually observed in root samples from grazed pastures compared with ungrazed pasture during the root washing process. Fine roots can make a very large contribution to the total root mass (Greenwood and Hutchinson, 1998). Dawson et al. (2000) stated that it is difficult to extract and discriminate live and active roots from inactive and dead roots and since root production and root mortality occur simultaneously, then root mass cannot be a strong reflection of below-ground growth.

Specific root length (cm/mg) is the root length produced by a unit of root mass. In this study, grazed pastures had nearly

47 and 45% less specific root length in LMG and SHG pastures, respectively (Tables 2 and 4). Arredondo and Johnson (2009) found that grazed plants with 80% removal of standing biomass produced half the specific root length compared to ungrazed plants. Conversely, Anderson and Hoffman (2007) indicated that clipping had no clear effect on the specific root length in *Andropogon greenwayi*, *Sporobolus kentrophyllus* and *Festuca idahoensis*. The higher value of specific root length was found in our study, where grazing was excluded. It may be attributed to root foraging, viz. the extension of the root system in search of soil nutrients due to limited resources and highly competitive conditions. Specific root length links to several morphological and physiological root variables such as increased root axis extension, proliferation (lateral growth), relative growth rate and resource uptake per unit mass. Specific root length showed negative correlations with root length, diameter and mass. Correlation coefficients ( $r$ ) of specific root length with root length, diameter and mass were 0.23, 0.34 and 0.57, respectively. These coefficients indicate that root mass followed by diameter had more effects on specific root length values. Wherever the root mass and/or diameter are higher, a higher specific root length would be expected. Consequently, the high value of specific root length in ungrazed pastures can be explained by those negative correlations. Higher specific root length value improves the ability of grasses to uptake more nutrients and water in competitive environments (Arredondo and Johnson, 2009). Specific root length was also affected significantly by soil depth (Tables 2 and 4). Specific root length increased with increasing soil depth. The deepest measured depth (20–30 cm) had the highest value of specific root length due to low root length, diameter and mass at this depth.

Since the pastures of both study areas remained strongly dominated by perennial grasses, i.e., there was no appreciable encroachment of invasive species; differences in root morphology and distribution as a result of cattle grazing in this study are attributable to responses by the perennial grass plants of itself. It should be emphasized that the results of root data interpretation in this study only indicate the presence of roots, not their functionality. The impact of grazing treatments on root morphology and distribution can be masked by the presence of old, non-functional roots or differing requirements for functionality to uptake ions. Consequently, root data should be interpreted with caution (Lodge and Murphy, 2006).

### Relationships between root traits and soil depths

There were strong relationships between root characteristics and soil depth in Signal grass under long-term moderate grazing and between root characteristics and soil depth for individual root samples of Carpet grass under short-term heavy grazing in various regression models as Linear, Exponential, Power and Logarithmic with moderate to high coefficient of denervation ( $R^2 > 0.50$ ) (Tables 6 and 7).

An exponential relationship between root length density and soil depth fits root data of both Carpet grass and Signal grass in this study. Our finding is supported by several authors, for example, Greenwood and Hutchinson (1998) and



**Table 8.** Distribution and spatial variability of root traits (Y) and soil depth (X) of the studied grass species.

| species      | Depth (cm) | RLD                               | SE    | % of total | RMD                              | SE    | % of total | RSAD                  | SE    | % of total | RVD                   | SE    | % of total |
|--------------|------------|-----------------------------------|-------|------------|----------------------------------|-------|------------|-----------------------|-------|------------|-----------------------|-------|------------|
| Carpet grass | 0 – 10     | 5.64                              | 0.439 | 72.86      | 2.79                             | 0.331 | 81.81      | 0.182                 | 0.065 | 52.29      | 0.01                  | 0.001 | 83.33      |
|              | 10 – 20    | 1.32                              | 0.247 | 17.05      | 0.472                            | 0.102 | 13.84      | 0.097                 | 0.020 | 27.87      | 0.001                 | 0.00  | 8.33       |
|              | 20 – 30    | 0.78                              | 0.306 | 10.07      | 0.148                            | 0.032 | 4.34       | 0.069                 | 0.027 | 19.82      | 0.001                 | 0.00  | 8.33       |
| Equation     |            | RLD = 3.25X+1.96                  |       |            | RMD = 2.11X+ 2.93                |       |            | RSAD = 0.790X+3.15    |       |            | RVD = 0.007X+3.25     |       |            |
|              |            | R <sup>2</sup> = 0.58             |       |            | R <sup>2</sup> = 0.70            |       |            | R <sup>2</sup> = 0.81 |       |            | R <sup>2</sup> = 0.69 |       |            |
| Signal grass | 0 – 10     | 4.18                              | 0.150 | 60.84      | 3.39                             | 0.369 | 69.04      | 1.16                  | 0.092 | 81.69      | 0.044                 | 0.010 | 91.66      |
|              | 10 – 20    | 1.88                              | 0.178 | 27.36      | 1.14                             | 0.149 | 23.21      | 0.16                  | 0.026 | 11.26      | 0.003                 | 0.001 | 6.25       |
|              | 20 – 30    | 0.81                              | 0.097 | 11.79      | 0.38                             | 0.093 | 7.73       | 0.10                  | 0.013 | 7.04       | 0.001                 | 0.00  | 2.08       |
| Equation     |            | RLD = 9.394e <sup>0.850</sup> (X) |       |            | RMD = 12.947e <sup>1.384</sup> X |       |            | RSAD = 1.14X+2.35     |       |            | RVD = 0.002X+2.35     |       |            |
|              |            | R <sup>2</sup> = 0.72             |       |            | R <sup>2</sup> = 0.75            |       |            | R <sup>2</sup> = 0.82 |       |            | R <sup>2</sup> = 0.82 |       |            |

RLD: root length density, RMD: root mass density, RSAD: surface area density, RVD: root volume density.

Oliveria et al. (2000) who reported exponential functions with coefficients of determination of 0.90, 0.74 and 0.98 for the relationship between grass root length density and soil depth, respectively.

In this study, R<sup>2</sup> values for exponential function were 0.58 and 0.72 for Carpet grass (tropical native grass) and Signal grass (tropical improved grass) with regard to root length density, respectively. Relatively low R<sup>2</sup> values in this study can be attributed to sampling depth, as in previously mentioned studies the sampling depth was much deeper than this study. The difference between R<sup>2</sup> values in the two study areas can be related to different rooting systems of grass species the rooting system of native and improved grasses are not similar. Overall, power and exponential functions depicted well the relationship between root distribution characteristics and soil depth for both species in this study.

Oliveria et al. (2000) cited that the relationship between the root mass density of Italian ryegrass (*Lolium multiflorum*) and soil depth by an exponential equation. The linear function was a poor predictor of the relationship between measured root distribution characteristics of improved pasture and soil depth among the functions. Greenwood and Hutchinson (1998) found that power and reciprocal functions were the strongest and the linear function was the poorest predictor in the description of root distribution and soil depth relationships in *Phalaris (Phalaris aquatica)* and White clover (*Trifolium repens*) pastures in NSW, Australia. Mousel et al. (2005) reported inverse relationships of big bluestem (*Andropogon gerardii*) root characteristics including root mass, surface area and volume densities with soil depth increment.

There were significant differences ( $P < 0.05$ ) between consecutive soil depth increments in the top 30 cm in all root traits at both studied species. Root variables of both grass species showed a higher proportion in 0 – 10 cm soil depth (Table 8). This indicates that the root system of both tropical grasses was largely distributed in surface soil depth. The higher proportion of grass plant roots in upper (0 – 10 cm) soil depth is supported by many researchers (for example, (Matthew et al., 1991; Greenwood and Hutchinson, 1998; Lodge and Murphy, 2006)).

### Conclusions

Defoliation of vegetation via grazing can be a major destructive process in pasture ecosystems. Knowledge of the response of both above- and below-ground processes of tropical pastures to grazing strategies is important to adjust the stocking rate. This study aimed to quantify the responses of both Signal grass and Carpet grass shoot and root systems to long-term moderate and short-term heavy, respectively, rotational grazing by cattle in tropical pastures. Our results indicate that shoot growth of studied grass plants tends to increase in pastures under both long-term moderate and short-term heavy grazing. Signal grass roots were not negatively affected by moderate grazing. Short-term heavy grazing had a higher impact on root characteristics than long-term moderate grazing. Besides grazing strategy, the response of shoot and root variables to grazing may also be contingent on other environmental variables, i.e., soil compaction, and soil texture and type. Consequently, the response of Signal grass and Carpet grass shoot and root systems to grazing may differ in other environments and needs to be investigated more. Overall, power and exponential functions depicted well the relationship between root distribution characteristics and soil depth for both species in this study. It should be emphasized that our findings in this study only indicate the presence of root variables, not their functionality. The impact of grazing on root morphology and distribution can be masked by the presence of old, non-functional roots or differing requirements for functionality to uptake ions.

#### Authors contributions

Authors have contributed equally in preparing and writing the manuscript.

#### Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

#### Conflict of interests

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.

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