



Biomass production and nutrient content of three agroforestry tree species growing on an acid Anthropic Ferralsol under recurrent harvesting at different cutting heights

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Received: 19 October 2018 / Accepted: 1 November 2019 / Published online: 29 January 2020
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Abstract Agroforestry systems may alleviate challenges relating to soil degradation and low livestock production for smallholder farmers. Species-adjusted management regimes will determine how agroforestry fits in farming systems. Long-term productivity of biomass in agroforestry systems managed for fodder production requires tree species that coppice after repeated cutting. This study evaluated the effect of different cutting heights (0.3 and 1.0 m) and repeated harvests (1–5) on biomass production and chemical composition of the leguminous trees *Acacia angustissima*, *Leucaena pallida* and *Mimosa scabrella* in a field study on an Anthropic Ferralsol in Southern Rwanda. Shoot biomass production was highest at 0.3 m cutting height for *A. angustissima* and *L. pallida*, but *M. scabrella* could not survive that cutting height.

Shoot biomass was highest for *A. angustissima* and lowest for *M. scabrella*, which did not adapt to repeated harvests. Leaf:stem ratio was not affected by cutting height. Cutting height did not affect crude protein (CP), but neutral detergent fibre (NDF), acid detergent fibre (ADF) and total polyphenol (TP) concentrations were higher at 1.0 m cutting height than at 0.3 m. Crude protein was highest in *A. angustissima* and lowest in *M. scabrella*, while NDF and ADF were highest in *M. scabrella*. Although all species provided high feed quality in terms of high CP content at both cutting heights, low cutting height (0.3 m) is recommended for *A. angustissima* and *L. pallida* for higher overall quality and biomass production.

Keywords Legume trees · Cutting height · Repeat-harvesting · Biomass production · Chemical composition

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Introduction

Increasing environmental degradation due to an increasing demand of food production and associated changes in land use has been identified as a key challenge to future livelihoods of smallholder farmers world-wide and especially in the tropics (Kang and Akinnifesi 2000). Studies indicate an accelerating decline in soil fertility due to a combination of high

rates of erosion, nutrient leaching, removal of crop residues and continuous cultivation of soil without adequate fertilisation or fallow (Mugwe et al. 2007). Considerable efforts, including fertiliser price subsidies, have been undertaken to make inorganic fertilisers affordable to farmers, but resource-poor farmers still cannot meet crop fertiliser requirements and have difficulties achieving and maintaining high productivity in intensively cropped farms (Partey 2011).

Practices such as integrated crop-livestock, conservation agriculture, agroforestry and nutrition-sensitive agriculture can significantly alleviate the above-mentioned challenges. However, they are effective only when applied in the right context and fitted to the overall production systems.

Multipurpose trees and shrubs are potentially valuable sources of protein-rich supplementary feed (Dzowela et al. 1995; Franzel et al. 2014; Kaitho et al. 1998; Norton 1994). Small-scale livestock farmers can use these to increase intake and digestibility of low-quality forages such as crop residues and mature tropical grasses, thus improving livestock nutrition and production (Azim et al. 2002; Luske and van Eekeren 2018; McMeniman et al. 1988).

Indigenous and exotic multipurpose trees and shrubs have been assessed for use in integrated crop and livestock agroforestry systems such as alley cropping (Chintu et al. 2004; Duguma et al. 1994; Kang et al. 1990). Based on criteria such as biomass production, chemical composition, potential for soil fertility improvement, forage production and diversity of niches, some promising species have been identified and disseminated to farmers.

In tropical regions, most farmers growing trees and shrubs use them for cut-and-carry as animal feeds and for green manure, fuelwood, poles and bean stakes (Mukuralinda et al. 2016). Hence, management of multipurpose trees and shrubs is probably informed by the primary objectives of farmers, i.e. whether they prioritise leafy or woody matter. The management regime will partly determine how trees can fit in farming production systems, and also their vigour and composition.

Acacia angustissima, *Leucaena pallida* and *Mimosa scabrella* are leguminous tree species often used in agroforestry systems, but information on their management and their response to cutting height and repeated cutting is scant. Therefore, this study assessed the effect of different cutting heights and

repeated cutting on biomass production and nutrient content in *A. angustissima*, *M. scabrella* and *L. pallida* growing on an acid Ferralsol in Southern Rwanda.

Materials and methods

Study area

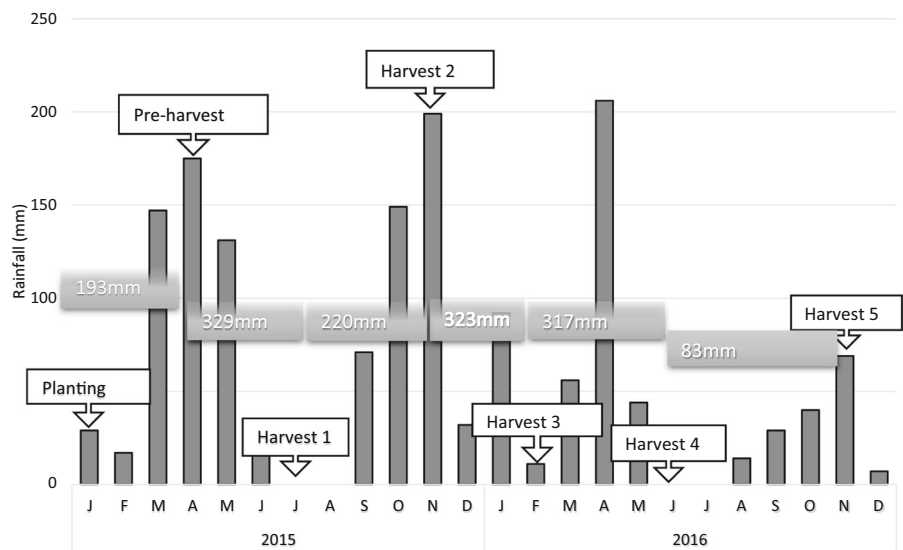
A trial was established at Tonga research station (2°35'S; 29°43'E; 1700 m above sea level), University of Rwanda, Southern Province, Rwanda. The site has a bimodal climate (Fig. 1), with mean annual temperature of 20 °C which is fairly constant throughout the year. Annual rainfall during the study period (973 mm in 2015, 568 mm in 2016) was lower than the long-term average (1200–1500 mm) (Ngarukiyimana et al. 2018). The soil at the site is a former Haplic Ferralsol changed to Anthropic Ferralsol (FAO 2006) due to radical terracing and has a sandy clay loam texture. Before the trial start, soil pH_{water} was 4.5, exchangeable Al³⁺ 3–4 cmol kg⁻¹, soil organic carbon 2%, total nitrogen 0.14% and phosphorus (Bray1) 2.8 ppm. The dominant pre-trial vegetation was *Eucalyptus* spp. and *Eragrostis curvula*. Land preparation was done by hoe and machete.

Seedling production and trial establishment

The trial had a 3 × 2 factorial arrangement in a randomised complete block design. The factors were three legume species (*A. angustissima*, *L. pallida*, *M. scabrella* Fig. 2) and two cutting heights (0.3 m, 1.0 m). Six blocks, each divided into six 10 m × 4 m plots, were established on six consecutive bench terraces, giving a total of 36 plots. Each tree species was grown in monoculture on plots separated by 2-m alleys.

Tree seeds were acquired from the Tree Seed Centre of Rwanda Water and Forestry Authority (RWFA) and sown in a nursery bed at the Tonga site. The soil mixture in the bed comprised equal parts local soil (sieved through a 10-mm mesh) and composted cattle manure. Germination occurred at 10–15 days and seedlings were transferred individually into polythene bags at approximately 3 weeks after emergence. The potting mixture was also local soil: compost, at a ratio of 70:30. The seedlings were initially raised under 60% shade netting, but shading and watering

Fig. 1 Rainfall during the study period (2015–2016) in mm per month (bars) and per growth period (overlay boxes) and timing of planting, bush creation and harvests. Rainfall was recorded at Butare Airport climate station, 3 km from the field trial



frequency were reduced as the seedlings grew. The shading was completely removed a few days prior to planting in the field trial, in order to harden off the seedlings. Seedlings were around 50 cm high at transplanting to the field trial. Cattle manure at a rate of 15 tons ha^{-1} and burned lime at a rate of 2 tons ha^{-1} were applied in the trenches 0.3 m wide and 0.4 deep 2 days before planting, to boost seedling establishment. Seedlings were planted in four rows, with 0.5 m spacing within rows and 1.0 m between rows, giving a total of 120 trees per plot. When the trees were approximately 1.50 m, all were uniformly cut to a height of 0.2 m above the soil, to stimulate shrubby morphology. Then, the following five cuts of regrowth were cut at 0.3 or 1.0 m above ground according to the experimental treatment. The following five cuts were made at either 0.3 or 1.0 m above ground

(experimental treatments). No further manure or fertiliser was added during the trial.

Sampling procedure

Net plots, excluding all trees in two border rows and all trees within 3 m from neighbouring plots, were used for data collection, in order to minimise edge effects. This gave an area of 18 m^2 with 36 trees per net plot. For each tree in net plots, data were collected on stump collar diameter at ~ 2 cm above the soil surface, shoot height, biomass production, leaf and stem production, leaf:stem ratio and survival rate at five occasions/harvests during the study period (Fig. 1). Stump collar diameter was measured at the base of each tree, just above ground level, using a calliper. Height to terminal bud on shoots was



Fig. 2 *A. angustissima*, *L. pallida* and *M. scabrella* species in field experiment (photo: Marguerite Mukangango)

determined with a measuring tape. Biomass was harvested manually in the net plots, using secateurs. Total fresh biomass of each regrowth period was weighed immediately after harvesting and then immediately separated into two fractions: leaves, twigs and succulent stems (< 8 mm diameter), a leafy fraction with potential use as forage, and the remaining material, a stem fraction. Fresh weight of both the leafy and stem fractions was immediately determined. Weighed subsamples of each fraction were then oven-dried at 60 °C for 72 h to constant weight before storage and laboratory analyses. The percentage water loss was used to calculate total dry weight yield of the plots. The leaf samples were milled to pass through a 1-mm screen before chemical analysis.

Survival status was taken as number of remaining living trees/number of originally planted seedlings \times 100. Trees were considered dead if found defoliated and/or dried. Harvests were timed to periods with reasonable amounts of regrowth, to reflect farmers' practice. The interval between two successive harvests varied between 3 and 5 months, depending on weather conditions (Fig. 1).

Chemical analyses

Crude protein (CP) was calculated as nitrogen (N) \times 6.25, where the N content was measured by the Kjeldahl method (AOAC, 1990). Folin-Denis reagent and the sodium carbonate method were used to determine content of total polyphenols (TP) (Anderson and Ingram 1993). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined as proposed by Van Soest et al. (1991). All data were expressed as kg dry matter (DM) or per g DM after correction by drying a subsample at 105 °C for 6 h.

Statistical analysis

The data were analysed as repeated-measures data. A mixed model approach as implemented in the mixed procedure of SAS (2012) was used. The relationships between harvest times within plots were modelled using an autoregressive covariance structure. The fixed factors in models were species, cutting height, harvest time and all interactions between these factors. Blocks were regarded as random variable. Separation

of means was done using the Tukey's range test when significant differences were indicated ($p < 0.05$).

Results

Biomass production parameters

Tree growth and biomass production parameters collar diameter of tree stumps increased over time and tended to be larger with 1.0 m cutting height than with 0.3 m. *Mimosa scabrella* had larger collar diameter than *A. angustissima* and *L. pallida* (Table 1).

Longer shoots were recorded for 0.3 m than 1.0 m cutting height (Table 1). Shoot length varied between harvests and was influenced by the amount and duration of precipitation of the growing period. *Acacia angustissima* showed the longest regrowth when tested across all harvest times, whereas *L. pallida* shoots were shortest except in harvest four.

Shoot biomass production was significantly higher at low cutting height when analysed across species and harvest times, although the cutting height effects were generally not significant for individual harvest times or species (Table 1). Higher shoot biomass production was obtained at lower (0.3 m) cutting for *A. angustissima* in the fourth and fifth harvests and for *L. pallida* in all harvests except the fifth, which showed no cutting height effect. In contrast, *M. scabrella* showed higher shoot production at high cutting height (1.0 m) in the fourth and fifth harvests. The highest shoot biomass production was obtained with *A. angustissima*, and this occurred at the third harvest. *Mimosa scabrella* established quickly and produced the highest biomass in the first harvest, but did not regrow as strongly as *A. angustissima* and *L. pallida* after the following harvests. In contrast, *L. pallida* initially had the lowest shoot biomass production, but yield increased from the third harvest and this species more biomass than in *M. scabrella* at the fourth and fifth harvests.

There was no significant effect of cutting height on leaf production when tested across species and harvest time. Tested across cutting heights, *A. angustissima* showed the highest leaf production in four harvests, while leaf production at the first harvest was highest for *M. scabrella* (Table 1).

Stem production was significantly affected by cutting height when tested across species and harvest

Table 1 Effect of cutting height and harvest time on regrowth parameters, leaf production, stem production and leaf:stem ratio in *A. angustissima*, *L. pallida* and *M. scabrella*. Values shown are LSM means

H.T	Species	C.H (m)	Collar Diam. (cm)	Shoot Length (cm)	Shoot biomass (TDM/ha)	Leaf (TDM/ha)	Stem (TDM/ha)	Leaf:stem ratio
1	A. <i>angustissima</i>	0.3	1.4 ^c	74.3 ^{cd}	2.1 ^{de}	1.1 ^c	1.0 ^{cd}	1.1 ^a
		1.0	1.4 ^c	49.1 ^d	2.1 ^{de}	1.2 ^c	0.9 ^d	1.3 ^a
	<i>L. pallida</i>	0.3	1.1 ^c	33.4 ^d	0.9 ^e	0.4 ^{cd}	0.5 ^{de}	0.8 ^a
		1.0	1.5 ^c	32.1 ^d	0.6 ^{ef}	0.3 ^d	0.2 ^{de}	1.5 ^a
	<i>M. scabrella</i>	0.3	1.8 ^c	74.1 ^{cd}	2.8 ^d	1.5 ^c	1.3 ^c	1.2 ^a
		1.0	2.3 ^{bc}	39.2 ^d	2.9 ^d	1.7 ^c	1.2 ^c	1.4 ^a
2	A. <i>angustissima</i>	0.3	1.8 ^c	106.3 ^c	2.0 ^{de}	1.0 ^c	1.0 ^d	1.0 ^a
		1.0	1.8 ^c	81.1 ^{cd}	2.0 ^{de}	1.1 ^c	0.9 ^d	1.2 ^a
	<i>L. pallida</i>	0.3	1.6 ^c	61.9 ^{cd}	1.1 ^e	0.5 ^{cd}	0.6 ^d	0.8 ^a
		1.0	2.0 ^c	40.9 ^d	0.6 ^{ef}	0.3 ^d	0.3 ^{de}	1.0 ^a
	<i>M. scabrella</i>	0.3	2.1 ^{bc}	68.5 ^{cd}	1.0 ^e	0.5 ^{cd}	0.5 ^d	1.0 ^a
		1.0	2.8 ^b	39.9 ^d	0.7 ^{ef}	0.4 ^{cd}	0.3 ^{de}	1.3 ^a
3	A. <i>angustissima</i>	0.3	2.3 ^{bc}	211.1 ^a	6.6 ^a	3.5 ^a	3.1 ^a	1.1 ^a
		1.0	2.4 ^{bc}	170.4 ^a	6.6 ^a	3.6 ^a	3.0 ^a	1.2 ^a
	<i>L. pallida</i>	0.3	2.1 ^{bc}	116.8 ^c	3.3 ^d	1.7 ^c	1.6 ^c	1.1 ^a
		1.0	2.5 ^b	88.3 ^c	2.5 ^d	1.4 ^c	1.1 ^{cd}	1.3 ^a
	<i>M. scabrella</i>	0.3	2.9 ^b	152.1 ^b	4.7 ^c	2.5 ^b	2.2 ^b	1.1 ^a
		1.0	3.2 ^b	89.4 ^c	2.7 ^d	1.6 ^c	1.2 ^{cd}	1.3 ^a
4	A. <i>angustissima</i>	0.3	2.6 ^b	203.2 ^a	5.9 ^a	3.1 ^b	2.8 ^a	1.1 ^a
		1.0	2.7 ^b	144.8 ^c	5.2 ^b	2.9 ^b	2.3 ^b	1.3 ^a
	<i>L. pallida</i>	0.3	2.6 ^b	86.9 ^c	3.1 ^d	1.5 ^c	1.6 ^c	0.9 ^a
		1.0	2.9 ^b	84.3 ^c	2.6 ^d	1.4 ^c	1.2 ^c	1.2 ^a
	<i>M. scabrella</i>	0.3	3.1 ^b	86.5 ^c	0.9 ^{ef}	0.5 ^{cd}	0.4 ^{de}	1.1 ^a
		1.0	3.5 ^{ab}	63.1 ^{cd}	2.0 ^{de}	1.1 ^c	0.9 ^d	1.3 ^a
5	A. <i>angustissima</i>	0.3	3.0 ^b	118.6 ^c	3.0 ^d	1.6 ^c	1.4 ^c	1.1 ^a
		1.0	3.1 ^b	82.8 ^{cd}	2.4 ^d	1.4 ^c	1.0 ^{cd}	1.4 ^a
	<i>L. pallida</i>	0.3	3.1 ^b	56.9 ^{cd}	0.8 ^{ef}	0.4 ^{cd}	0.4 ^{de}	1.0 ^a
		1.0	3.2 ^{ab}	45.3 ^d	0.8 ^{ef}	0.5 ^{cd}	0.4 ^{de}	1.3 ^a
	<i>M. scabrella</i>	0.3	3.9 ^a	74.7 ^{cd}	0.4 ^{ef}	0.2 ^d	0.2 ^c	1.0 ^a
		1.0	4.1 ^a	46.2 ^d	0.7 ^{ef}	0.4 ^d	0.3 ^{de}	1.3 ^a
<i>p</i> value	Species		<.0001	<.0001	<.0001	<.0001	<.0001	0.4247
	C.H		0.0002	<.0001	0.0143	0.7442	0.0076	0.8617
	H.T		<.0001	<.0001	<.0001	<.0001	<.0001	0.3521
	Species × C.H × H.T		0.136	0.035	0.0264	0.0928	0.0067	0.9688

TDM/ha tons of dry matter per ha, CH cutting height, HT harvesting time. Means within columns followed by different superscript letters are significantly different at *p* < 0.05

times. The highest production was generally observed at low cutting height (0.3 m), except for *M. scabrella* at the fourth and fifth harvests, which showed higher stem production at high cutting height (1.0 m) (Table 1).

Leaf production was not affected by cutting height, while stem production decreased at 1.0 m cutting height. The consistently higher average leaf:stem ratio at 1.0 m cutting height reflected the changes in stem

production at different cutting heights, although the differences in leaf:stem ratio were not significant.

The number of shoots per tree was similar for both cutting heights for *A. angustissima* and *L. pallida* (Fig. 3). In contrast, *M. scabrella* cut at 0.3 m showed the had more shoots per tree than cut at 1.0 m at the first harvest, but the number of shoots numbers in later harvests declined sharply when trees was cut at 0.3 m.

Acacia angustissima and *L. pallida* exhibited almost 100% survival at the five harvest times (Fig. 4). From the third harvest onwards, the number of *M. scabrella* decreased after each harvest and the largest loss occurred at 0.3 m cutting height (Fig. 4).

Chemical composition of the leafy fraction

Cutting height had no significant effect on DM and CP content (Table 2). However, when tested across all species and harvests, the highest NDF, ADF and TP values were observed at 1.0 m cutting height, although differences in general were not significant for individual harvests or species. *Acacia angustissima* had the highest CP concentration, whereas the highest NDF and ADF concentrations were recorded in *M. scabrella* (Table 2). However, there was considerable variation between replicates and differences were not always significant in individual harvests. Plant composition also differed between harvests when tested across species and cutting heights; CP concentrations

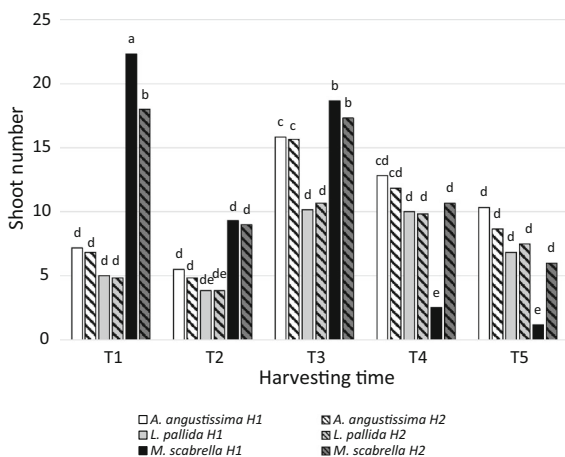


Fig. 3 Effect of cutting height and harvest time on number of shoots per tree in *A. angustissima*, *L. pallida* and *M. scabrella*. T1 to T5: harvests time; H1: cutting height at 0.3 m; H2: Cutting height at 1 m. LSMeans, bars with different superscript letters are significantly different at $p < 0.05$

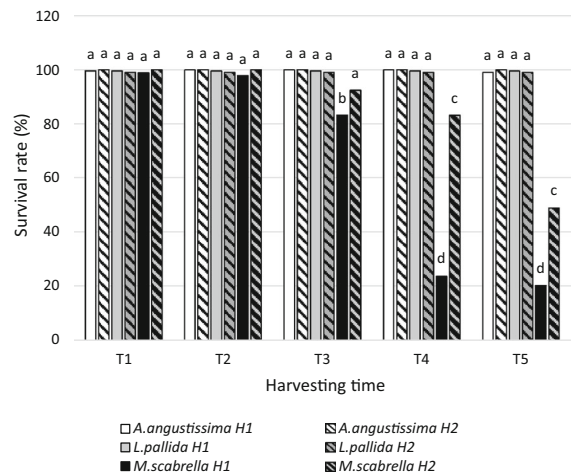


Fig. 4 Effect of cutting height and harvest time on survival rate of *A. angustissima*, *L. pallida* and *M. scabrella*. T1 to T5: harvest time; H1: Cutting height at 0.3 m; H2: Cutting height at 1.0 m. LSMeans, bars with different superscript letters are significantly different at $p < 0.05$

were highest in harvest two and lowest in harvest five, whereas the concentrations of NDF, ADF and TP tended to be lowest in harvests two and four and highest in harvest five.

Discussion

Biomass production parameters

One of the major challenges to optimize the production of legume tree species in agroforestry systems is the information on site specific management practices (Holzmueller and Jose 2012) e.g. appropriate species, cutting height harvesting time etc. Although there was no clear effect of cutting regime on shoot biomass accumulation in this study, the overall trend was for somewhat higher shoot biomass production at low cutting height for *A. angustissima* and *L. pallida*, but lower biomass for *M. scabrella* after repeated harvests. Previous studies reported no, small or varying effects of cutting height for a range of tree species. Isah et al. (2014) obtained larger *Moringa oleifera* biomass at lower cutting (0.2 m) than higher cutting (1.0 m) under drier conditions of Maradi, Niger, while an increase in biomass production with increasing cutting height has been observed for *Gliricidia sepium* and *Leucaena leucocephala* (Duguma et al. 1988) and

Table 2 Effect of cutting height and harvest time effect on leaf nutrient content in *Acacia angustissima*, *Leucaena pallida* and *Mimosa scabrella*. Values shown are LSMMeans

H.T	Species	C.H (m)	DM (%)	CP (%)	NDF (%)	ADF (%)	TP (%)
1	<i>A. angustissima</i>	0.3	93.8 ^a	29.5 ^a	54.7 ^{bc}	46.6 ^c	1.2 ^{ab}
		1.0	92.9 ^a	29.8 ^a	60.7 ^b	52.6 ^{ab}	1.3 ^a
	<i>L. pallida</i>	0.3	93.6 ^a	24.7 ^{ab}	54 ^{bc}	46.0 ^{bc}	1.3 ^a
		1.0	93.6 ^a	23.2 ^b	64.3 ^b	53.0 ^{ab}	1.5 ^a
	<i>M. scabrella</i>	0.3	94.7 ^a	26.8 ^{ab}	65.8 ^b	58.6 ^a	1.4 ^a
		1.0	94.2 ^a	22.5 ^b	74.1 ^a	63.5 ^a	1.6 ^a
2	<i>A. angustissima</i>	0.3	94.0 ^a	31.0 ^a	52.7 ^{bc}	44.9 ^{bc}	1.1 ^{ab}
		1.0	94.4 ^a	32.6 ^a	57.3 ^{bc}	50.7 ^{ab}	1.2 ^{ab}
	<i>L. pallida</i>	0.3	93.2 ^a	28.7 ^a	47.3 ^{bc}	41.3 ^{bc}	1.3 ^a
		1.0	93.6 ^a	30.0 ^a	52.3 ^{bc}	49.7 ^{ab}	1.4 ^a
	<i>M. scabrella</i>	0.3	94.0 ^a	25.6 ^{ab}	58.6 ^b	49.6 ^{ab}	1.4 ^a
		1.0	93.4 ^a	26.3 ^{ab}	67.1 ^{ab}	58.5 ^a	1.5 ^a
3	<i>A. angustissima</i>	0.3	92.5 ^a	30.3 ^a	52.7 ^{bc}	46.0 ^{bc}	1.2 ^{ab}
		1.0	92.4 ^a	32.6 ^a	58.7 ^b	51.7 ^{ab}	1.2 ^{ab}
	<i>L. pallida</i>	0.3	92.1 ^a	28.9 ^a	54.0 ^{bc}	48.7 ^{ab}	1.6 ^a
		1.0	91.7 ^a	26.8 ^{ab}	63.0 ^b	56.7 ^{ab}	1.8 ^a
	<i>M. scabrella</i>	0.3	91.0 ^{ab}	20.8 ^{bc}	71.6 ^a	60.0 ^a	1.4 ^a
		1.0	92.1 ^a	19.2 ^{bc}	75.6 ^a	65.5 ^a	1.6 ^a
4	<i>A. angustissima</i>	0.3	92.6 ^a	31.2 ^a	47.0 ^{bc}	40.3 ^{bc}	1.3 ^{ab}
		1.0	92.6 ^a	32.3 ^a	53.7 ^{bc}	47.0 ^{abc}	1.3 ^a
	<i>L. pallida</i>	0.3	92.7 ^a	28.8 ^a	40.3 ^{bc}	34.0 ^c	1.3 ^a
		1.0	92.6 ^a	28.3 ^a	46.0 ^{bc}	40.7 ^{bc}	1.5 ^a
	<i>M. scabrella</i>	0.3	93.2 ^a	20.2 ^{bc}	55.1 ^b	49.5 ^{ab}	1.0 ^b
		1.0	93.3 ^a	20.2 ^{bc}	68.6 ^{ab}	61.5 ^a	1.2 ^{ab}
5	<i>A. angustissima</i>	0.3	90.9 ^{ab}	26.1 ^{ab}	63.8 ^{ab}	54.5 ^{ab}	1.5 ^a
		1.0	91.4 ^{ab}	28.4 ^a	73.15 ^a	60.2 ^a	1.3 ^a
	<i>L. pallida</i>	0.3	91.0 ^{ab}	25.9 ^{ab}	40.3 ^c	51.3 ^{ab}	1.2 ^{ab}
		1.0	91.2 ^{ab}	24.5 ^{ab}	61.9 ^b	51.3 ^{ab}	1.7 ^a
	<i>M. scabrella</i>	0.3	92.2 ^a	19.8 ^{bc}	71.1 ^a	67.3 ^a	1.7 ^a
		1.0	92.3 ^a	19.2 ^{bc}	83.9 ^a	71.3 ^a	1.6 ^a
<i>p</i> -value	Species		0.0278	<.0001	<.0001	<.0001	<.0010
	C.H		0.9911	0.5911	<.0001	<.0001	0.0181
	H.T		<.0001	<.0001	<.0001	<.0001	0.0002
	Speciesx C.H × H.T		0.4691	0.492	0.1813	0.811	0.3431

C.H: Cutting height; H.T: Harvesting time; DM: Dry matter; CP: crude protein; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; TP: total polyphenol. Means within columns followed by different superscript letters are significantly different at $p < 0.05$

Tephrosia diversipholia (Partey 2011) under tropical climate. Niang et al. (1994) detected an increase in biomass production on moving from low cutting (0.25 m) to high (0.75 m) for some species, including *M. scabrella*, corroborating the findings here. However, they found no cutting height effects for other species, neither did Erdmann et al. (1993) find any effect of cutting height on biomass production in *G. sepium*.

In the present study, *A. angustissima* produced more shoot biomass than *L. pallida* and *M. scabrella*. The mean annual shoot production calculated from the five harvests (Table 1) was of 9.9 and 10.7 tons ha⁻¹ - year⁻¹ for *A. angustissima* cut at 0.3 and 1.0 m respectively. This was higher than the 3–7.4 tons ha⁻¹ year⁻¹ and 0.4–5.4 tons ha⁻¹ year⁻¹ reported by Nyoka et al. (2012) at two Zimbabwean research stations with mean annual rainfall of 880 and 895 mm, respectively. The calculated annual leaf

production of *L. pallida* of 2.2 and 2.8 tons ha⁻¹ year⁻¹ for 0.3 and 1.0 m cutting heights respectively, was higher than the 1.0 tons ha⁻¹ year⁻¹ found by Akyeamong (1998) when cutting *L. pallida* at 12 months of age in a study on acid soils in Burundi. However, the mean annual leaf biomass production of *M. scabrella* of 2.8 tons ha⁻¹ year⁻¹ was considerably less than the 13–22 tons m⁻¹ year⁻¹ reported by Niang et al. (1994) for hedgerows on high-elevation acid soils of Rwanda. Nevertheless, its rapid establishment at Tonga site as well as the high shoot biomass production of *M. scabrella* at different pruning heights observed by Niang et al. (1994) confirm its high capability to withstand acid soils.

The variations in shoot biomass production observed between growing periods for all species in this study were most caused by variations in weather, especially rainfall, during the trial. For example, the lower shoot biomass at the second, fourth and fifth harvests is explained by lower rainfall recorded during these growing periods than in the first and third periods (Fig. 1 and Table 1). Orwa et al. (2009) found that *A. angustissima* can grow well under rainfall of 895–2870 mm year⁻¹ and has the capacity to withstand dry periods up to 8 months, that *L. pallida* can grow well under 500–1000 mm year⁻¹ and can withstand dry periods up to 7 months, and that *M. scabrella* can grow well under 600 mm year⁻¹ but can only withstand dry periods up to 4 months.

The decline in *M. scabrella* biomass production and survival rate during the fourth and fifth regrowth periods indicates inability of this species to withstand multiple harvests. Similarly, Bakke et al. (2009) reported non-adaptation of *Mimosa tenuiflora* to annual pruning of all sprouts, which led the trees to perish. Low tree survival rate is probably linked to depletion of carbohydrate reserves during the recovery phase (Karim et al. 1991). These reserves are crucial to support initial regrowth (Latt et al. 2000). Partial defoliation and increased interval between harvests could probably minimise the mortality of *M. scabrella* shrubs and maximise their production (Bakke et al. 2009). Early onset of harvesting in the present study, induction shrubby morphology at 4 months and first harvest at 7 months after planting, could be another factor in low resistance to repeated cuttings. Niang et al. (1994) found that *M. scabrella* responded well to frequent cuttings when the first cutting occurred 9 months after planting and at 1 m cutting height.

Further studies are needed to determine whether the effect of cutting height and repeated harvests is similar for old and newly established stands of *M. scabrella*.

Leaf:stem ratio varies depending on relative production of leaves and stems. For forage plants, it is important that leaf:stem ratio is greater than 1 (Calado et al. 2016). This ratio exerts a great influence with regard to animal nutrition, since the nutrient content and digestibility is generally higher in leaves than in stems (Casanova-Lugo et al. 2014). The species tested here all had leaf:stem ratio > 1 at both cutting heights except *L. pallida*, which showed leaf:stem ratio < 1 at 0.3 m. This shows that *A. angustissima*, *L. pallida* and *M. scabrella* generally produced larger amounts of leaves than stems.

Composition of the leafy fraction

The CP content was high in all species tested and was not affected by cutting height. The CP content in *A. angustissima* and *L. pallida* was higher than reported by Abdulrazak et al. (2000) for different *Acacia* spp. and by Mutimura et al. (2013) for *L. pallida*. The range of CP content in *M. scabrella* (Table 2) was not far from that (24.9%) reported by Niang et al. (1996). In all cases, the CP content of *A. angustissima*, *L. pallida* and *M. scabrella* at both cutting heights was greater than 19% and, based on this, the leafy fraction can be classified as prime fodder (Kazemi et al. 2012). Hence these tree species are suitable protein supplements to low-quality basal diets.

The fibre content of all three species was high compared with literature values (Hove et al. 2001; Mutimura et al. 2013; Rubanza et al. 2005), but lower than reported by Diriba et al. (2013). Total polyphenol content was much lower than reported by Rubanza et al. (2005) for *A. angustissima* grown in Tanzania and by Mutimura et al. (2013) for *L. pallida* grown in Rwanda. However, our values were similar to those found by other researchers (Mokoboki 2011; Rubanza et al. 2006) and by Salem et al. (2013) for browse tree species classified as good supplements for low CP forage. Furthermore, due to the TP content being below the 5% threshold suggested by Wassie and Abebe (2013), the tree legumes in our study can also be valuable as green manure for growing crops, thus providing another potential use on farms.

Selection of appropriate tree species and biomass harvest methods depends on a number of factors,

including the purpose of the agroforestry practices, the tree component prioritised, arrangement of the trees relative to food crops and the resources available, especially labour. *Acacia angustissima* and *L. pallida* appear to be robust species for use in agroforestry systems with biophysical conditions and cutting methods similar to those in this study. *Acacia angustissima* showed advantages over the other species tested in terms of quick establishment, tolerance to repeated cuttings at different height, rapid recovery and contributing most to high biomass production and nutritional composition. *Mimosa scabrella* established rapidly, but did not survive repeated cutting and hence produced biomass for a shorter period.

Conclusions and recommendations

Acacia angustissima and *L. pallida* performed better than *M. scabrella* on a weathered Anthropic Ferralsol in Southern Rwanda. In general, shoot biomass was higher when *A. angustissima* and *L. pallida* were harvested at 0.3 m cutting height compared with 1.0 m.

Crude protein content and leaf:stem ratio did not differ significantly with cutting height. However, mean NDF and ADF and TP tended to be higher at 1.0 m cutting height and mean shoot biomass production was higher at low cutting height (0.3 m). Therefore, low cutting height should be recommended to farmers for higher-quality fodder and higher shoot biomass production.

Mimosa scabrella did not survive repeated harvests. Further studies are needed to determine whether higher age at first harvest, longer interval between harvests and partial defoliation could maximise production and minimise mortality. Further studies are also recommended on the degradability of the leafy fraction used to supplement low-quality grass feeds or as green manure to improve soil fertility.

Acknowledgements Open access funding provided by Swedish University of Agricultural Sciences. We thank the Swedish International Development Agency (Sida) for financial support through the UR-Sweden programme for Research, Higher Learning and Institutional Advancement, and University of Rwanda (UR), Swedish University of Agricultural Sciences (SLU) and those who contributed to this study. We thank the

reviewers for valuable comments and constructive criticism that has contributed to an improved manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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