

## Research Article

# *Acacia sieberiana* Effects on Soil Properties and Plant Diversity in Songa Pastures, Rwanda

C. P. Mugunga<sup>1</sup> and D. T. Mugumo<sup>1,2</sup>

<sup>1</sup> National University of Rwanda, P.O. Box 56, Huye, Rwanda

<sup>2</sup> Université Libre de Kigali, Rubavu Campus, P.O. Box 243, Gisenyi, Rwanda

Correspondence should be addressed to C. P. Mugunga; mugungac@yahoo.co.uk

Received 3 July 2013; Accepted 9 September 2013

Academic Editor: Curtis C. Daehler

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Effects of *A. sieberiana* trees on soil properties and plant diversity were investigated in Songa pastures, Rwanda. Tree characteristics and crown architecture of *A. sieberiana* were studied. Soil properties were assessed and plants were identified under and away from tree crowns. Counts of individual plants/species were done only under tree crowns. Nitrogen, P, and K were analysed in the soil, grass, and *A. sieberiana* leaves. Plant diversity was determined using Simpson's diversity index. Data were subjected to ANOVA. Soil organic carbon (SOC), cation exchange capacity (CEC), Ca<sup>2+</sup>, N and pH, and plant diversity were higher in soils under tree canopies than in open areas. Tree leaves were significantly richer in N and poorer in P and K as compared to grasses. Tree crowns grew wider and horizontal and developed intertwined secondary branching, reducing light intensity to as low as 38% under tree canopies compared to the open pasture. At 3 trees/ha stocking, *A. sieberiana* trees shaded 0.18 ha and herbaceous plants and grasses unpalatable to livestock dominated under tree canopies. A tradeoff of *A. sieberiana* tree value versus the loss of palatable grass due to tree presence needs to be assessed to decide whether the trees should be included in pastures and if yes, the appropriate stocking identified.

## 1. Introduction

The incorporation or retention of trees into farming systems is an old tradition in Africa. This makes a basis of what is often referred to as agroforestry [1]. Trees in such systems fulfil a lot of functions and services [2]. They may provide shelter to soils, plants, and livestock and may increase soil organic matter and sometimes soil nitrogen content. Being perennial, tree functions and their influence on the site may be cumulative [3]. A few or a group of trees are usually left deliberately or planted on land under some other main use in which case trees fulfil a secondary role [4].

It is well known that some trees may deplete soil resources and this is more severe with some exotic species, for example, *Eucalyptus* [5], which compete with other plants for soil moisture [5–7] and for soil nutrients [8–10]. More often, some tree species negatively interfere with biodiversity, leading to a decline in plant diversity [11]. This tendency is sometimes attributed to allelopathy [12–14]. Some plant species may

improve soil properties [15] and yet deplete biodiversity. Even the best trees in soil improvement may be detrimental to biodiversity, especially when planted at a narrow spacing where the reduction in the amount of light reaching the ground may suppress shade intolerant plants [16].

Trees capture and return leached nutrients to the crops' rooting zone [17] through processes known as the safety net [18] and the nutrient pump [19], respectively. In doing so they can affect soil pH by reducing or increasing it depending on tree species. Ryan and McGarity [20] found that pH decreased under *Eucalyptus grandis* canopies. Increase in soil pH is clearly significant for production, as Munnich et al. [21] found that the frequency of the nutritious and palatable native grass *Microlaena stipoides* increased with lower soil pH.

*Acacia* species in general are multipurpose trees providing a wide range of products and services [22]. The tree is socially accepted because it provides fuel, fodder, gum, and local medicine to farmers among others. *A. sieberiana* is reported to be one of the most commonly used browse tree

species in arid and semiarid regions of Africa [23, 24] as it has good feeding qualities. Indices among other factors include the species' low insoluble proanthocyanidins and high soluble phenolics [25]. Soils under a variety of tree species are often higher in nitrogen, phosphorus and other nutrients [26–29]. *Acacia* litter contributes greatly to soil fertility due to the tree's ability to fix atmospheric nitrogen [30]. In arid and semiarid areas, the soils beneath the *Acacia* canopy are usually better developed than those outside the canopy, having higher nitrogen and water contents [31]. Nitrogen fixing ability of the tree makes it one of the most suitable species for agricultural fields [32].

In Rwanda, *Acacia sieberiana* remnant trees are left in pastures for shade or fodder or planted in home gardens for ornamental purposes [33]. Managed pasture has emerged as an important land use system in the postgenocide period. Although animal rearing in pastures is more prominent in the savannah woodlands of the eastern province, it is practiced in other parts of the country as well. Changes in land use have recently led to a profound reduction in woodland structure and tree cover where tree patches or individual trees which have survived tree cutting are seen in pastures, in crop farms, and in home gardens. One of the most remarkable tree species which can be seen in pastures is *Acacia sieberiana* DC.

Despite their acknowledged benefits, there is no management plan or clear policy guidelines on the management of such trees or their impacts on the main features of site characteristics, particularly the soil and biodiversity. This is because they have not been studied for their influence on soil characteristics and plant diversity under pasture management, at least under local conditions. Furthermore, the architecture of *A. sieberiana*'s crown is very low and very broad, imparting a significant shading effect to the ground and plants underneath its canopy. The aim of this study was to assess the crown architectural characteristics of *A. sieberiana* trees and the resultant shading effects and the influence on soil properties and plant diversity in Songa pasture, southern Rwanda. The results may then be applied to the pastures in the eastern province, a region which has a higher population of *A. sieberiana* trees in similarly managed pastures.

## 2. Materials and Methods

This study was conducted at the Songa Research Station of the Rwanda Agriculture Board from December 2011 to March 2012. According to Manzi et al. [34], the station is located in the mid-altitude zone (1500–1600 masl) of Rwanda (2°24'S, 29°46'E), with average annual temperature ranging between 22°C and 29°C, an average annual rainfall of 1087 mm (1237 mm according to [35]), and relative humidity of 77%. The rainfall pattern is bimodal, with short rains (season A) falling between September and December and long rains (season B) extending from March through May. The dry season extends between June and August, sometimes to September. The rain is heavy in April–May, decreasing gradually until October. The natural vegetation consists of natural grass dominated by *Brachiaria decumbens*. The pasture is scattered by trees of *A. sieberiana* traditionally used to supply shade to the livestock during hot days.

Soil sampling and plant identification were done in systematically demarcated plots. For this purpose, the whole pasture was divided into four blocks and four *A. sieberiana* trees were randomly selected in each block to make a total of 16 sample trees. Circular sample plots of 1 m diameter each were laid 3 m apart along two perpendicular transects running from each *A. sieberiana* tree trunk to the periphery of the crown in north and east directions. Of the 16 sample trees, 10 trees had 10 sample plots each and six trees had eight plots each, giving a total of 148 sampling points that were used for soil sampling and plant counts under tree canopies.

From the sample trees, four traits were measured, namely, breast height diameter (DBH), crown diameter ( $K$ ), height-to-crown base ( $H_{CB}$ ), and branch tip height above the ground ( $H_{BT}$ ). Individual tree DBH was measured using a diameter tape. A tape measure was used to measure  $K$  as the diameter of the crown shade projected to the ground when the sun was overhead at noon. From the latter, the area shaded by the crown ( $A$ ) was computed as the area of a circle whose diameter equals  $K$ .  $H_{CB}$  and  $H_{BT}$  were measured by using a tape measure by putting its zero end on the ground and stretching it to the base of the branch and to the tip of the branches, respectively. For measuring  $H_{CB}$  and  $H_{BT}$ , four lower branches attached to the main stem in approximately four cardinal directions were taken in each sample tree. To get more insight on the branching characteristics of the species, extra assessments were made. One tree was selected per block and the following traits were measured:  $K$ , total tree height ( $H_{TOT}$ ),  $H_{CB}$ , and  $H_{BT}$ . During growth, *A. sieberiana* tree branches usually undergo a series of successive deaths followed by development of new or secondary branches. Secondary branch lengths (internodes) ( $L_I$ ) per branch were measured using a tape measure, done by climbing the tree using a ladder and measuring the length of the branch part between two death (and regrowth) points. This enabled us to get the total count of internodes/branch ( $N_I$ ) and the sum of all  $L_I$ /branch gave the total branch length ( $L_{Br}$ ).

To assess the intensity of shade by *A. sieberiana* trees, the amount of light was measured both under and outside the tree canopies. For this purpose, the four sample trees used for extra tree trait measurements said above were used. LI-COR quantum sensors (LI-COR 1000) were laid along the transects explained above from the tree base to 30 m which is about double the crown radius. Six sensors were spaced at five meters such that three were under the tree canopy at the tree base (0 m), at mid crown (7.5 m), and at the crown periphery (15 m) while the other three were located in the open pasture at 20, 25, and 30 m away from the tree base. Assessments were made for three consecutive days from August 7–9, 2013, and from each sensor, readings were taken six times per day at 6, 8, 10, 12, 14, 16, and 18 h. This period is the dry season, which is characterized by very little cloud cover. Light measurements were recorded as photosynthetic photon flux density (PPFD) ( $\mu\text{M m}^{-2} \text{s}^{-1}$ ).

In order to compare plant species that occurred under and away from the tree crowns and the effect of *A. sieberiana* trees on soil chemical and physical properties, plant identification and soil sampling were also done in the area under grass outside the tree crowns. Transects explained above were

extended to double their length such that 1/2 the transect length was covered by the *A. sieberiana* crown while the other 1/2 was outside the tree crown. In this extended distance outside the tree crowns, sampling points similar and equal in size and number to those demarcated under the tree crowns were established.

For all soil sample collection, sampling was done in the top (0–10 cm) soil layer using an auger. All plant species occurring in the plots both under and away from the crowns were botanically identified, but a physical count of individuals per species was done only in the plots under the tree crowns. Soil parameters of interest included particle size distribution, soil organic carbon (SOC), exchangeable calcium ( $\text{Ca}^{2+}$ ), and soil pH. Soil and foliar nutrient analyses were done using standard procedures as explained by Okalebo et al. [36]. Leaf nutrients tested included total N, P, and K.

For statistical analyses, all measured variables were subjected to an analysis of variance to assess differences between treatments. Levene's test was used to test for homogeneity of variance. Statistical significance was determined at  $P < 0.05$  and differences among treatments were separated using the LSD test. All analyses were performed using SPSS 17.0 software for Windows. Biodiversity was determined by using Simpson's index of diversity (1D).

### 3. Result and Discussion

**3.1. Soil Properties.** The sand proportion was significantly higher ( $P < 0.05$ ) away from *A. sieberiana* canopy (70%) than under the canopy (65%) (data not presented). This difference might be due to a positive contribution of the trees to soil improvement, owing to leaf litter and root turnover. Litter addition usually improves soil aggregate stability by binding soil particles together [37]. Furthermore, the soil outside the tree canopies dries out faster as a result of being more exposed to direct solar radiation. This not only accelerates thermally induced soil organic matter decomposition but also results in the shrinking of organic matter and clay colloids, thereby making the soil more compact [38].

Results of soil chemical properties are shown in Table 1. Soil pH, soil N, SOC, and  $\text{Ca}^{2+}$  improved significantly under the canopy probably due to the presence of *A. sieberiana* trees. The overstory may facilitate forage species, for instance, by improving soil conditions, as for crops in agroforestry [39]. This is in agreement with the findings by Sirois et al. [40]. Generally speaking, all soils of Rwanda have a low pH [41, 42] and this condition limits nutrient availability [43]. The incorporation of trees in farming systems as sources of litter partly aims at increasing soil pH. This has been one of the major practices in agroforestry systems [44]. *A. sieberiana*, as trees that have been standing in the study area for a long time, may have significantly contributed to the improvement in soil pH and other soil properties.

The accumulation of organic matter and nutrients in the soils under tree canopies as found in this study might have several origins. These may include litter falling from the trees, root turnover, animal defecation as they stay under shade for browsing and/or rest during hot periods, and decay of shade

tolerant plants that grow prolifically under the canopy [22, 37, 45, 46].

**3.2. Tree Sizes and Crown Shade.** The total pasture area was 310 ha and the average stocking was 3 *A. sieberiana* trees/ha. All trees in the study area were mature and neither seedlings nor saplings were observed. Average tree traits were observed to be: 148.3 cm for DBH (range: 100.6–180.0 cm), 27.7 cm for  $K$  (range: 21.4–34.0 m), 0.061 ha for  $A$  (range: 0.036–0.091 ha), 3.4 m for  $H_{BC}$  (range: 1.8–5.4 m), and 2.5 m for  $H_{BT}$  (range: 1.5–4.1 m). Traits related to the crown architecture are shown in Table 2. Tree sizes reported here are within the range reported for the species [47]. It should be noted here that branch length is the summation of all internode lengths per branch and these are directly linked to  $K$ .

*A. sieberiana* trees shade a big ground area under tree canopies. The pasture area shaded by an average *A. sieberiana* tree was observed to be 0.06 ha. The shading capacity was observed to be a result of such architectural characteristics of the crown as the size, branch network, and the height above the ground. The tree is characterised by low branching and its branches experience successive death of branch tips followed by the development of one or more secondary branches (internodes) emanating in different directions from the previous death point. This process leads to the development of a twined branch network which, together with tall branches ( $L_{Br}$  of about 10–16 m), constitutes a broad crown. Usually the secondary branch height (and therefore the crown height) above the ground increases from near the branch base (at 1–5 m) to a certain maximum at about half the branch length. The height then drops outwards to the tip of the branch ending up with a branch tip height (1.5–4 m) equal to or less than the branch base. This leads to naturally very low and flattened tree crowns which appear as mushroom- or umbrella-like shapes in *A. sieberiana*.

This crown architecture causes a strong shading effect on the ground underneath tree canopies. The light levels at 0, 7.5, and 15 m from the tree base were found to range from 38, 60 to 85% (average 61%), respectively, of the values in the open pastures. The three distances corresponded to middle, halfway, and the periphery of *A. sieberiana* tree crown from the tree base (Table 3). While a mesh-like network of its branches alone could suffice to keep the area under its crown shaded even if all the leaves were shed, the tree sheds only a small proportion of its leaves during the dry seasons rendering it to remain evergreen all year round. These facts make it an effective shelter tree to livestock especially in arid and semiarid areas during the dry seasons.

The photosynthetic photon flux density (PPFD) recorded under the tree canopy ( $328\text{--}746 \mu\text{M m}^{-2} \text{s}^{-1}$ ) and in the open pastures in this study ( $857\text{--}878 \mu\text{M m}^{-2} \text{s}^{-1}$ ), even at points furthest (30 m) from the tree base, is lower than the normal range for full light which normally ranges from 1200 to  $2000 \mu\text{M m}^{-2} \text{s}^{-1}$  [48]. Light levels recorded in this study are only slightly higher than those reported under agroforest canopy, said to be usually around  $800 \mu\text{M m}^{-2} \text{s}^{-1}$  [48] except under highly closed forests where light can be as low as  $50 \mu\text{M m}^{-2} \text{s}^{-1}$  [49, 50].

TABLE 1: Chemical characteristics of the top (0–10 cm) soil layer under and outside the canopies of *Acacia sieberiana* trees in Songa pasture, southern Rwanda.

Soil properties	Means under tree canopy ( $n = 48$ )	Means under open area ( $n = 48$ )	
pH	$5.79 \pm 0.13$	$5.44 \pm 0.08$	*
N (%)	$0.90 \pm 0.06$	$0.63 \pm 0.05$	*
C (%)	$4.76 \pm 0.31$	$3.63 \pm 0.29$	*
P (ppm)	$45.01 \pm 5.72$	$31.54 \pm 4.14$	NS
Ca <sup>2+</sup>	$9.81 \pm 0.55$	$4.14 \pm 0.56$	*
K <sup>+</sup>	$0.46 \pm 0.03$	$0.58 \pm 0.09$	NS
Mg <sup>2+</sup>	$1.91 \pm 0.10$	$1.94 \pm 0.21$	NS

\*and NS denote, respectively, significant and nonsignificant differences among means for soils under and away from tree crowns ( $P < 0.05$ ).

TABLE 2: *Acacia sieberiana* crown architecture: crown diameter ( $K$ ), total tree height ( $H_{TOT}$ ), height from the ground to the crown base ( $H_{CB}$ ), height from the ground to the branch tip ( $H_{BT}$ ), branch length ( $L_{Br}$ ), branch internode length ( $L_I$ ), and the number of internodes/branch ( $N_I$ ) in Songa pastures, southern Rwanda.

Tree no.	Branch no.	$K$ (m)	$H_{Tot}$ (m)	$H_{CB}$ (m)	$H_{BT}$ (m)	$L_{Br}$ (m)	$L_I$ (m)	$N_I$
1	1	24.6	6.1	5.1	0.9	15.2	1.1	15
	2				1.5	11.5	0.6	18
	3				2.2	12.8	1.0	16
	4				2.0	12.6	0.6	20
2	1	27.2	8.1	3.0	1.3	15.7	1.1	16
	2				5.2	15.8	0.9	18
	3				5.3	12.5	0.9	18
	4				3.1	9.7	0.5	20
3	1	24	7.8	1.0	2.6	13.1	1.0	19
	2				1.5	15.7	1.0	19
	3				1.4	14.4	1.0	18
	4				1.7	15.8	0.9	17
4	1	26.9	6.9	4.4	2.1	15.0	0.8	19
	2				1.3	11.4	0.6	18
	3				1.6	10.3	0.5	19
	4				1.4	9.7	0.5	20
Average		25.7	7.2	3.4	2.2	18.1	13.2	0.8
Range		24.0–27.2	6.1–8.1	1–5.1	0.9–5.3	9.1–15.8	0.5–1.1	15–20

High shading intensity is, however, not always beneficial since it may influence the microclimate and hence the soils and biodiversity under the tree crowns [11, 16]. At an average stocking rate of 3 trees/ha observed in this study, a corresponding area shaded by the crown was 0.183 ha, an 18% of a hectare. With an observed tendency of unpalatable plant species growing under *A. sieberiana* trees (Table 5) and assuming a uniform production rate of grasses throughout the pasture, a stocking of 3 *A. sieberiana* trees/ha would lead to 18% reduction in the yield of palatable grasses.

*A. sieberiana* trees are usually used as fodder for animals and they become more important in dry seasons and more so in arid regions when shelter to animals is of great value and grasses in the pastures decline significantly in quantity and in quality [23]. *A. sieberiana* is reported to have higher crude protein than a number of other species [51]. It could be possible that fodder value of *A. sieberiana* trees may compensate for losses in palatable grass yield resulting from growing or retaining the trees in pastures. This however needs

to be ascertained through research. The study area however is reasonably wet and cool and the importance of shelter may not be that important. In addition, fodder harvesting from *Acacia* trees may not be an easy undertaking since young branches with pods and tender leaves need to be cut every time they have to be supplied to the animals as fodder.

**3.3. Foliar Analysis.** The quantities of the major nutrients (N, P, and K) obtained through folia analyses are presented in Figure 1. As would be expected, significant differences ( $P < 0.05$ ) were observed in nitrogen contents in *A. sieberiana* tree leaves compared to the grasses outside the tree influence, with a higher nitrogen percentage being observed in tree leaves than in the grasses. An inverse situation was observed for potassium which was significantly ( $P < 0.05$ ) more concentrated in grasses than in *A. sieberiana* tree leaves. Phosphorus had slightly higher values in grasses than in trees, but did not differ statistically from those obtained in *A. sieberiana* leaves.

TABLE 3: Light intensity measured at six locations (0, 7.5, 15, 20, 25, and 30 m) from *Acacia sieberiana* tree base in Songa pasture southern Rwanda. Upper table shows measurements expressed as % of light relative to open pasture; lower table measurements are expressed as photosynthetic photon flux density ( $\mu\text{M m}^{-2} \text{s}^{-1}$ ).

Time	Sensor identity (distance from tree base, m)					
	1 (0)	2 (7.5)	3 (15)	4 (20)	5 (25)	6 (30)
6:00	38.4	62.6	84.8	99.4	97.3	100.0
8:00	39.3	60.0	83.6	98.7	99.2	100.0
10:00	35.7	61.5	84.1	95.4	96.0	100.0
12:00	37.2	68.2	85.3	99.4	99.9	100.0
14:00	37.2	60.1	88.3	98.4	99.9	100.0
16:00	37.7	60.1	81.0	98.5	100.2	100.0
18:00	38.0	45.5	85.9	93.5	99.7	100.0
Average	37.6	59.7	84.7	97.6	98.9	100.0
		60.7*			98.8**	
6:00	215.4	351.2	475.5	557.4	545.6	560.7
8:00	265.3	405.5	564.7	666.9	670.3	675.5
10:00	373.5	642.4	878.8	997.6	1003.1	1045.2
12:00	470.6	862.4	1078.8	1257.2	1262.4	1264.2
14:00	463.5	748.9	1101.4	1227.4	1245.7	1246.9
16:00	299.3	477.7	643.6	782.4	795.6	794.4
18:00	211.6	253.5	478.5	521.2	555.5	557.3
Average	328.5	534.5	745.9	858.6	868.3	877.7
		536.3*			868.2**	

Overall average light: \*under tree canopy and \*\* in open pasture.

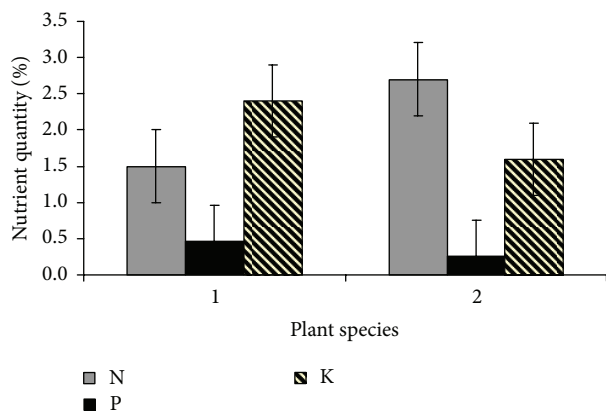


FIGURE 1: Nitrogen, P, and K (%) obtained from species 1 (grass) and from species 2 (*A. sieberiana*) leaves in Songa pastures, southern Rwanda. Vertical bars represent standard errors of the means ( $n = 48$ ).

The higher concentration of nitrogen in *A. sieberiana* tree leaves than in grass is presumably due to the ability of many acacias to fix atmospheric nitrogen [52]. This attribute makes them suitable for agricultural fields and for incorporation in agroforestry systems [32]. The lack of statistical differences between tree and grass leaves in phosphorus content may not be surprising. Both *Acacia* and grasses are known to live in association with vesicular arbuscular mycorrhizal fungi (VAM) [4].

3.4. *Plant Diversity.* Plants that grew under *A. sieberiana* tree canopy were mainly herbaceous, differed in life forms, and were easy to separate and count, while those which grew outside the canopy were dominated by *Brachiaria* grass and were not easy to sort out individually (Figure 2). Niche preference differed between plant species and some plants were exclusively found either under the tree canopy or outside the tree canopy while others were common in both niches (Table 4). For the species that occurred exclusively under *A. sieberiana* tree canopy, the average number of individuals per species ranged from 0.1 to 693 (Table 4). *Setaria homonyma*, the only grass species in this group, had the highest number followed by *Tagetes minuta* and the rest of the species had very low numbers of individuals per species (Table 5). Like all plant species identified under *A. sieberiana* tree canopy, *S. homonyma* was unpalatable to the cattle.

Overstory competition is reported to reduce forage production in the understory [53, 54]. In addition, constraining the light and nutrients available to the understory could shift plant composition toward species tolerant of shade and nutrient stress [55]. Stress tolerant species tend to have “conservative” life history strategies emphasizing conservation of resources over rapid growth, while fast-growing “acquisitive” species often require productive conditions [56]. Reduced photosynthetic and growth rates of conservative species are usually associated with low nutrient content [57] and high content of structural and defensive compounds [58] such as lignin that can moreover reduce their quality as forage [59, 60]. Plant species interactions change with environmental condition, and can shift over time as conditions change. For

TABLE 4: Species and families found in Songa pasture, southern Rwanda (data collected from 148 sample plots under *A. sieberiana* tree canopies and from 148 plots outside the tree canopy area).

No	Botanical name	Family
1	<i>Acacia sieberiana</i> DC.*	Mimosoideae
2	<i>Achyranthes aspera</i> L.*	Amaranthaceae
3	<i>Aspilia pluriseta</i> Schweinf.***	Asteraceae
4	<i>Asystasia gangetica</i> (L.) T. Anders.**	Acanthaceae
5	<i>Bidens pilosa</i> L.*	Asteraceae
6	<i>Brachiaria decumbens</i> Stapf.***	Poaceae
7	<i>Brachiaria eminii</i> (Mez) Robyns**	Poaceae
8	<i>Brachiaria platynota</i> (Schum.) Robyns***	Poaceae
9	<i>Clerodendrum rotundifolium</i> *	Verbenaceae
10	<i>Commelina diffusa</i> Burm. f.**	Commelinaceae
11	<i>Conyza sumatrensis</i> Retz. ex Walker*	Asteraceae
12	<i>Cyathula uncinulata</i> (Schrad.) Schinz.**	Amaranthaceae
13	<i>Cynodon dactylon</i> L.**	Poaceae
14	<i>Cyperus rigidifolius</i> Steud.***	Cyperaceae
15	<i>Cyperus rotundifolius</i> Steud.***	Cyperaceae
16	<i>Desmodium barbatum</i> (L.) Benth. var. <i>procumbens</i> Schub.***	Papilionoideae
17	<i>Desmodium salicifolium</i> (Poir)***	Papilionoideae
18	<i>Desmodium setigerum</i> (E. Mey) Benth***	Papilionoideae
19	<i>Desmodium setigerum</i> (E. Mey) Benth.***	Papilionoideae
20	<i>Dichondra repens</i> J. R. & G. Forst.***	Convolvulaceae
21	<i>Dichondra repens</i> G. R. & G. Forst.***	Convolvulaceae
22	<i>Dichondra repens</i> J. R. & G. Forst.***	Convolvulaceae
23	<i>Galinsoga parviflora</i> Cav.*	Asteraceae
24	<i>Hibiscus</i> sp.***	Malvaceae
25	<i>Hyparrhenia filipendula</i> (Hochst. Ex Steud.) Stapf.***	Poaceae
26	<i>Indigofera spicata</i> Forssk.***	Papilionoideae
27	<i>Indigofera spicata</i> Forssk.***	Papilionoideae
28	<i>Justicia matamensis</i> (Schweinf.) Oliv.***	Acanthaceae
29	<i>Kyllinga bulbosa</i> P. Beauv.*	Cyperaceae
30	<i>Leonotis nepetifolia</i> (L.) Ait**	Lamiaceae
31	<i>Mariscus sumatrensis</i> (Retz) Rayn.***	Cyperaceae
32	<i>Mariscus sumatrensis</i> (Retz.) J. Rayn.***	Cyperaceae
33	<i>Monechma subsessile</i> (Oliv.) C.B. Cl.***	Acanthaceae
34	<i>Neonotonia wightii</i> (Wight & Arn.) Lackey***	Papilionoideae
35	<i>Neonotonia wightii</i> (Wight & Arn.) Lackey**	Papilionoideae
36	<i>Ocimum suave</i> Willd.**	Lamiaceae
37	<i>Pennisetum clandestinum</i> Chiov.*	Poaceae
38	<i>Phyllanthus pseudoniruri</i> Muell. Arg.**	Euphorbiaceae
39	<i>Pycneus nitidus</i> (Lam.) J. Rayn.***	Cyperaceae
40	<i>Rubia cordifolia</i> L.***	Rubiaceae
41	<i>Ruellia patula</i> Jacq.*	Acanthaceae
42	<i>Setaria homonyma</i> (Steud.) Chiov.*	Poaceae
43	<i>Setaria</i> sp.*	Gramineae
44	<i>Sida rhombifolia</i> L.**	Malvaceae
45	<i>Sporobolus pyramidalis</i> P. Beauv.***	Poaceae
46	<i>Tagetes minuta</i> **	Poaceae
47	<i>Triumfetta rhomboidea</i> Jacq.***	Tiliaceae

\*Species that occurred under the tree canopies; \*\*species that occurred in both niches; \*\*\*species that occurred outside the tree canopies.

TABLE 5: Populations of 11 plant species recorded under canopies of *A. sieberiana* trees in Songa pastures, southern Rwanda.

Species\tree no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
<i>Setaria homonyma</i>	683	1037	115	806	972	637	1210	395	528	478	1001	240	826	816	594	756	693
<i>Tagetes minuta</i>	525	213	321	80	304	250	129	107	215	420	347	291	226	185	336	183	258
<i>Galinsoga parviflora</i>	182	0	197	12	203	168	83	27	65	39	78	107	128	85	48	75	94
<i>Achyranthes aspera</i>	17	60	194	67	101	29	46	29	73	66	48	125	78	48	29	92	69
<i>Leonotis nepetifolia</i>	88	11	38	8	71	59	32	90	74	54	27	46	56	82	96	63	56
<i>Asystasia gangetica</i>	91	24	12	0	26	37	31	26	9	28	18	5	16	32	26	30	26
<i>Bidens pilosa</i>	0	0	0	16	0	4	0	0	1	1	0	0	0	0	0	0	1
<i>Cyathula uncinulata</i>	0	13	0	0	0	0	0	0	3	0	0	0	4	0	0	0	1
<i>Rubia cordifolia</i>	0	0	1	0	0	0	0	0	0	1	1	2	0	0	5	0	1
<i>Conyza sumatrensis</i>	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0.2
<i>Acacia sieberiana</i>	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0.1

instance, competition is frequently weakened and vice versa for facilitation under conditions of abiotic stress [61, 62] and disturbance such as grazing [63]. Facilitation could particularly benefit resource-demanding “acquisitive” species, likely of higher quality as forage due to higher nutrient content and lower content of structural and defensive compounds [55].

Simpson’s index values under the canopy were high and ranged from 0.88 to 0.97 implying a high level of plant diversity. Some new species under tree crowns invaded the pastures and replaced grasses originally managed for cattle grazing. These species are usually found in agricultural fields and examples include *Bidens pilosa*, *Conyza sumatrensis*, and *Tagetes minuta*. There is likelihood that alien plant species, which are likely more competitive than the pasture species [64], have attracted an even higher animal and microbial diversity [65] thereby increasing the overall landscape biodiversity in the pastures. Unfortunately these alien plant species, most of which are annual herbs, seemed unpalatable to cattle since they remained intact throughout the rainy season at the end of which they died a natural death. The presence of *A. sieberiana* trees in the pastures and its association with nonpalatable invasive plant species, therefore, results in the reduction of effective pasture area that is used to produce cattle basal feed, the grasses.

*Setaria homonyma* which dominated the area under tree canopy was absent in the pasture area away from tree canopies. This may be attributed to it being a shade demanding grass species. Its exclusive occupation under the canopy may indicate how the light conditions under canopy are very important in determining plant dominance. The rest of the species identified under the tree canopy did not occur in the open pasture but did occur in open agricultural fields in which case they are weeds or grow in other frequently disturbed areas. This is very interesting because agricultural lands are usually exposed to direct solar radiation and plant species in them are expected to be light demanders. On the other hand, those occurring under *A. sieberiana* trees are expected to be shade bearers since they received solar radiation reduced as low as 38% of the amount in the open areas. Despite being very important, light levels may therefore not be the only major cause of change in plant species composition under *A. sieberiana* tree crowns. Other factors

such as soil moisture and water stress may play a great role as well. Trees are known to take up environmental resources in their vicinity thereby outcompeting annual plant species growing near them [66–68].

The soils under the canopy appeared as a disturbed, loose and with annually dying and decaying plants. This happens every year leaving the floor bare or semibare during the dry seasons with plants emerging again in the majority of cases during the early next rain season. This microhabitat enables a suite of species that are shade tolerant and not adapted to strong competition as occurred in the grass dominated open pasture outside the tree crowns, thus enriching overall biodiversity [69].

**3.5. Lack of Natural Regeneration in *A. sieberiana*.** It is particularly surprising that *A. sieberiana* had only one seedling recorded once in the whole pasture area (310 ha) and no saplings were observed. Poor regeneration in native trees has been raised as a concern and might be exacerbated by climate change. This casts doubt on the survival and population increase in *A. sieberiana* outside deliberate human intervention. One of the most likely causes of poor regeneration in this species is probably the total absence of wild fires. Wild fires characterize savannah woodlands of Africa and play a role in the regeneration of trees through breaking seed dormancy [16, 70]. Many studies have confirmed a dormancy relief in legume seeds after fire [71–79].

On environmental protection grounds, bush fire is banned on the Rwandan territory. This may be justified for soil and water conservation purposes. However, some plant species may be disadvantaged as long as natural regeneration is concerned. The distribution of plant species is often thought to be dependent upon environmental effects on germination and seedling establishment [80]. The connection between germination, seedling survival, and distribution of leaves opens the possibility that other environmental factors that affect germination success may influence the distribution and existence of the species [81]. Poor to no regeneration was also noted in other Rwandan acacias studied recently, especially where soils have never been disturbed. While trampling and browsing by grazing animals in the pastures could also lead to the lack of recruitment by *A. sieberiana*



FIGURE 2: Diversity and life forms of plant species identified under *Acacia sieberiana* trees and in its surroundings: (a) open pastures, (b) under tree canopy, and (c) both under and away from the tree canopy.

trees, the area surrounding the pastures where animals are not allowed to graze freely does not have *A. sieberiana* saplings as well.

#### 4. Conclusions

Circumstances that lead to isolated trees in Rwanda are increasing due to ecosystem fragmentation and changes in land use. This requires proper policy on the management of both the trees and the ecosystems. The knowledge generated in this study is relevant both for policy makers and pasture managers. Some useful characteristics of crown architecture in *A. sieberiana* that determine its shading intensity, plant species, and diversity under their canopy, which had never been considered important and thus not quantified, have now been characterized. These include branch length, heights of the crown base above the ground, the number of branches, and height of branch tips above the ground. Light levels under *A. sieberiana* tree canopies at 0, 7.5, and 15 m from the tree base were found to be 38, 60, and 85% (average 61%) of its magnitude in the open pastures, respectively. The three distances corresponded to the middle, halfway, and the periphery of *A. sieberiana* tree crown, respectively.

As observed, *A. sieberiana* trees have a positive influence on soil physical and chemical properties besides the already known value of providing fodder and shade for livestock, especially during dry seasons in arid and semiarid areas. Furthermore, some ecologically useful services can be made available by the presence of *A. sieberiana* trees in the pastures. The trees may increase biodiversity at landscape level. The amount of light was observed to influence species niche preference, but soil moisture and water stress (not assessed in this study) may also play a role in this respect. However, the trees shade the area under canopies thereby promoting the growth of plants seemingly unpalatable to livestock. This may reduce the effective pasture area that yields palatable grasses for livestock feeding. Grasses constitute the basal feed for the livestock. The area potential for producing palatable grass affected by one *A. sieberiana* tree/ha was observed to be 600 m<sup>2</sup>. At an average stocking recorded in this study of 3 trees/ha, the ground shaded by the tree crowns which would therefore not produce palatable grasses was 1,800 m<sup>2</sup> (18% of one hectare).

Some studies are recommended to fill the gaps observed in this study. These include, losses in the yield of palatable grasses in relation to the shading effect of *A. sieberiana* trees, fodder quantity and quality of both the palatable grasses and *A. sieberiana* trees and if the latter can compensate for losses in the yield of palatable grasses encountered due to the presence of the trees in the pastures shelter value of *A. sieberiana* trees in the pasture, and the appropriate stocking of these in relation to palatable grass production.

#### Acknowledgments

This paper combines an M.S. thesis research and additional study on *A. sieberiana* at the National University of Rwanda (NUR). The authors sincerely thank the Swedish International Development Agency for funding this work through the National University of Rwanda Research Directorate. Very sincere and heartfelt thanks are due to the late Eson Munyanziza for his invaluable contribution to this study. May the Lord rest his soul in eternal peace. C. K. Ruffo's contribution in plant identification is highly valued.

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