Original article – Thematic Issue

Integration of shade-tolerant forage legumes under enset [*Ensete ventricosum* (Welw.) Cheesman] plants in south-western Ethiopia

Z. Yemataw[1], K. Tawle[1], M. Bolton[2], R. Kebede[3] and G. Blomme[2]

[1] The Southern Agricultural Research Institute [SARI], Areka, Ethiopia
[2] Bioversity International, P.O. Box 5689, c/o ILRI, Addis Ababa, Ethiopia
[3] Independent consultant, Addis Ababa, Ethiopia

Summary

Introduction – **Mature enset plants (*i.e.*, plants in the latter stage of their growth cycle) are mainly grown in sole-cropping. In order to boost biomass production per unit area, the integration of shade-tolerant or shade-loving plant species that provide food, feed or biomass for mulch could be envisaged.** *Materials and methods* – **In this study, ten shade-tolerant forage legumes were evaluated for their growth and biomass production when grown under mature enset plants in south-western Ethiopia. The forage legumes were established as intercrops at the onset of the rainy season (*i.e.*, July) and planted in rows with enset, both on farm and on station, using 3 replications per legume species. In addition, growth and biomass yield of legumes were assessed when grown as sole crops. The ability of intercropped legume species to survive the long 6- to 7-month dry season was also assessed. Although rainfall levels during the dry season months do not suffice to sustain legume plant growth, no irrigation took place at the various trial sites.** *Results and discussion* – **Some forage legumes (*Macrotyloma axillare, Centrosema pubescens*, *Pueraria phaseoloides, Lablab purpureus, Chamaecrista rotundifolia, Vicia villosa* and *Vigna unguiculata*) produced moderate to high amounts of above-ground biomass yield under intercropping conditions, and this especially during the second/third consecutive legume cropping seasons. For example, fresh legume biomass yields of 11 to 15 t ha^{-1} were obtained at the Areka intercropping trials during the second legume cropping season. Fresh biomass yield of up to 22.9 t ha^{-1} was recorded for *C. pubescens* under enset during the third consecutive cropping season at Areka. Some forage legumes that were able to survive the prolonged dry seasons (*M. axillare*, *D. intortum*, *C. rotundifolia*, *C. pubescens*, *D. uncinatum* and *P. phaseoloides*) grew vigorously during the subsequent rainy seasons, due to the established roots and lower stem sections which survived the dry season. The forage legume *M. axillare* is very promising as it not only grew vigorously in both the sole-cropped and intercropped fields, but it also survived the extended dry season and quickly re-sprouted at the onset of the rains. Feedback from farmers in the Lemo and Angacha districts, where on-farm trials were conducted, indicated that some forage legumes, *e.g.*, *M. axillare* and *D. intortum*, could be integrated into plots of mature enset plants, suggesting that farmers' selection criteria go beyond biomass production level. Farmers also indicated that various shade-tolerant weed species produce significant amounts of biomass in mature enset fields, thus providing additional options for biomass production under shade.** *Way forward* – **Further multi-location and multi-year on-farm evaluations of the most promising forage legume species and surveys should be carried out to determine edible and high-yielding weed species currently growing in mature enset fields.**

Significance of this study

What is already known on this subject?

- Mature enset plants (*i.e.*, plants in the latter stage of their growth cycle) are mainly grown in sole-cropping.

What are the new findings?

- Various shade-tolerant forage legumes (*e.g.*, *Macrotyloma axillare*, *Centrosema pubescens*, *Pueraria phaseoloides,...*) grow well as intercrops in mature enset fields, and contribute to whole farm biomass/feed production.

What is the expected impact on horticulture?

- Enhanced livestock production through additional sources of feed. Enhanced soil fertility through the application of mulch and manure.

Keywords
above-ground biomass, animal feeding, drought tolerance, enset, Ethiopia, integrated crop management, intercropping

Résumé

Intégration de légumineuses fourragères tolérantes à l'ombre sous culture d'ensète [*Ensete ventricosum* (Welw.) Cheesman] dans le sud-ouest de l'Ethiopie.

Introduction – **Les plantes matures (*i.e.*, celles qui se trouvent au dernier stade de leur cycle de croissance) sont principalement cultivées en monoculture. Afin de stimuler la production de biomasse par unité de surface, il a été envisagé d'intégrer des espèces**

végétales tolérantes à l'ombre ou aimant l'ombre qui fournissent de la nourriture, des aliments pour animaux ou de la biomasse pour le paillage. *Matériel et méthodes* **– Dans cette étude, dix légumineuses fourragères tolérantes à l'ombre ont été évaluées pour leur croissance et leur production de biomasse lorsqu'elles sont cultivées sous culture d'ensètes matures dans le sud-ouest de l'Ethiopie. Des légumineuses fourragères ont été établies comme cultures intercalaires en début de saison des pluies (*i.e.*, en juillet) et ont été plantées en ligne avec l'ensète, à la ferme et en station, en utilisant 3 répétitions par espèce de légumineuse. La croissance et le rendement en biomasse des légumineuses ont été évalués lorsqu'elles sont cultivées en monoculture. La capacité des espèces de légumineuses intercalées à survivre pendant la longue saison sèche de 6 à 7 mois a également été évaluée. Les niveaux de précipitations pendant les mois de saison sèche ne suffisent pas à soutenir la croissance des légumineuses, mais aucune irrigation n'a eu lieu sur les différents sites d'essais.** *Résultats et discussion* **– Certaines légumineuses fourragères (*Macrotyloma axillare*, *Centrosema pubescens*, *Pueraria phaseoloides*, *Lablab purpureus*, *Chamaecrista rotundifolia*, *Vicia villosa* et *Vigna unguiculata*) ont produit des quantités modérées à élevées de biomasse aérienne dans des conditions de culture intercalaire, en particulier pendant les deuxième et troisième saisons de culture de légumineuses consécutives. Par exemple, des rendements de biomasse de 11 à 15 t ha^{-1} de légumineuses fraîches ont été obtenus lors des essais de culture intercalaire à Areka au cours de la deuxième saison de culture de légumineuses. Une production de biomasse fraîche allant jusqu'à 22,9 t ha^{-1} a été enregistrée pour *C. pubescens* sous ensètes au cours de la troisième saison de culture consécutive à Areka. Certaines légumineuses fourragères aptes à survivre à des saisons sèches prolongées (*M. axillare*, *D. intortum*, *C. rotundifolia*, *C. pubescens*, *D. uncinatum* et *P. phaseoloides*) se sont développées vigoureusement pendant les saisons des pluies suivantes, grâce à un système racinaire bien établi et des sections inférieures de tige qui ont survécu à la sécheresse. La légumineuse fourragère *M. axillare* est très prometteuse dans la mesure où non seulement elle a poussé vigoureusement dans les champs en culture unique ou en culture associée, mais elle a également survécu à la saison sèche prolongée et a repoussé rapidement au début des pluies.** *Conclusion* **– Dans leurs commentaires, les agriculteurs des districts de Lemo et d'Angacha, où les essais à la ferme ont été menés, ont indiqué que certaines légumineuses fourragères, telles que *M. axillare* et *D. intortum*, pourraient être intégrées dans des parcelles d'ensètes matures, suggérant que les critères de décision des agriculteurs vont au-delà de la seule production de biomasse. Ils ont aussi mentionné que diverses espèces de mauvaises herbes tolérantes à l'ombre produisaient des quantités importantes de biomasse dans les champs d'ensètes matures, offrant ainsi des options supplémentaires pour la production de biomasse à l'ombre. Des évaluations supplémentaires des espèces de légumineuses fourragères les plus prometteuses devraient être menées en milieu paysan sur plusieurs sites et sur plusieurs années, et des enquêtes devraient être conduites pour déterminer les espèces d'adventices comestibles à haut rendement qui poussent actuellement dans des champs d'ensètes matures.**

Mots-clés
alimentation animale, biomasse aérienne, culture associée, ensète, Ethiopie, gestion intégrée des cultures, tolérance à la sécheresse

Introduction

The total area covered by enset plants has more than quadrupled over the last 50 years from around 65,000 ha in the 1960's (Stanley, 1966) to around 300,000 ha in 2010 (CSA, 2011). Various enset cropping systems exist (Brandt *et al.*, 1997; Abebe, 2005). For example, young enset plants are often intercropped with annual crops (*e.g.*, maize, potato, vegetables and herbs). Mature enset (*i.e.*, enset plants in the final stages of their life cycle) is often intercropped with coffee and multipurpose trees on smallholder farms. However, intercropping mature enset with annual crops is rare.

Plots allotted to mature enset plants occupy on average 20–30% of the total enset plots in enset-based cropping system (Zeberga *et al.*, 2014). Due to the high shade levels provided by the enset leaf canopy, commonly grown annual food and feed crops do not perform well when intercropped with mature enset. Most farmers are unaware of other shade-tolerant feed or food crops that could potentially be introduced and grown under shade.

There is a high demand for animal feed as most enset smallholder farms have at least one cow and/or bull. Crop residues (*e.g.*, maize) and weeds which grow in mature enset fields and other locations on the farmland are fed to the animals during the rainy seasons (Brandt *et al.*, 1997). In addition to its use as a source of carbohydrate-rich human food, enset is also utilized as animal feed. Fresh enset leaves contribute to livestock diets in all regions where enset is grown (Tolera, 1990; Fekadu, 1996), mainly during the dry season *i.e.*, for a 7 to 8-month period (Yilma, 2001), or even throughout the whole year (Karin and Alemu, 1995) in some agro-ecological areas, such as the highlands of Sidama and Gedeo. Occasionally, the whole enset plant is chopped up and fed to livestock during the dry seasons (Tolera, 1990; Fekadu, 1996; Desta and Oba, 2004). Enset corms and pseudostems were found to be poor with respect to crude protein intake as well as N retention when fed as sole diets (Fekadu and Ledin, 1997; Nurfeta *et al.*, 2008a). There is, hence, a need to supplement a corm and pseudostem diet with protein-rich feeds, such as hay from forage legumes or enset leaves (Nurfeta *et al.*, 2008b).

Due to the high population density (estimated at 300–350 inhabitants km^{-2}) and related high land pressure (less than 0.5 hectare per household), banana-legume intercropping is widely practiced in east and central Africa (DSRP, 2005; CIALCA, 2010). Land use efficiency of smallholder banana farms in east and central Africa can be enhanced through the incorporation of food and/or fodder legumes (Sileshi *et al.*, 2007). These legumes contribute to weed suppression, maximizing field/plot productivity and minimizing risks related, *e.g.*, to climate change (Nyabyenda, 2006; Dapaah *et al.*, 2003; Zinsou *et al.*, 2004; Amanullah *et al.*, 2007). In addition, intercropping with nitrogen-fixing legumes contributes to increasing soil fertility levels (Chakeredza *et al.*, 2007).

A similar approach using shade-tolerant forage legumes could be envisaged for intercropping/integration under mature enset plants. In this study, 10 promising forage legume species which have been extensively reported in literature to be shade tolerant and often also drought tolerant were selected for evaluation in mature enset plots.

Centrosema pubescens has been adopted as a green manure and ground cover in plantation crops in Java, Sumatra, peninsular Malaysia and Sri Lanka (Teitzel and Chen Chin Peng, 2016). Since the 1950's, *C. pubescens* has also been widely used as a plantation cover and pasture legume in the Pacific Islands, the wet tropics of Australia and indeed much of the humid tropics worldwide (Plucknett, 1979; Pushparajah, 1982; Schultze-Kraft and Clements, 1990; Ng, 1990). *C. pubescens* is drought-tolerant because of its deep root system, making it capable of using groundwater if no other water is available (Parbery, 1967; Skerman *et al.*, 1988; FAO, 2013a). *Centrosema pubescens* can survive a dry season of 3–4 months (Teitzel and Chen Chin Peng, 2016). However, during prolonged drought, the plant adapts by dropping its leaves (Heuzé and Tran, 2016). *Centrosema pubescens* is also capable of enduring shade, and was reported to still persist under 80% shade (Heuzé and Tran, 2016). Seedling growth is slow under shady conditions, but mature plants tolerate shade (FAO, 2013a). Schultze-Kraft and Clements (1990) reported that *C. pubescens* is only moderately shade-tolerant as the species behaves as a sun species and exhibits a linear decrease in growth with increase in shade. Similarly, Wong (1990), Wong *et al.* (1985) and Manidol (1984) reported that *C. pubescens* is moderately shade-tolerant.

Desmodium intortum (greenleaf) has good shade tolerance (Shelton and Stür, 1991; Cook *et al.*, 2005; Hacker, 1992; Skerman *et al.*, 1988; ILRI, 2013b; Cook, 1984; Eriksen and Whitney, 1982; Whiteman *et al.*, 1974). Eriksen and Whitney (1982) reported that *D. intortum* and *C. pubescens* had intermediate reductions in dry matter yield (t ha^{-1} $year^{-1}$) when grown at 70 and 45% of full sunlight. For example, *D. intortum*'s proportional biomass yields at 70% and 45% of full sunlight were 93 and 75%, respectively. Significant reductions in biomass yield of *D. intortum* and *C. pubescens* were observed when grown at 27% of full sunlight, producing respectively 46% and 44% of full sunlight biomass yields. *Desmodium intortum* has a poor tolerance to drought (FAO, 2013b; Baijukya, 2004), and is susceptible to extended dry spells. It carries little foliage in the dry season, when most of the leaves drop and form a mulch (Horrell, 1958). However, *D. intortum* wilts less fast compared to *Desmodium uncinatum* (Ostrowski, 1966).

Desmodium uncinatum (silver leaf) needs rainfall exceeding 1,000 mm with good distribution throughout the year. Although not productive during the dry season, it persists in regions with dry seasons of 3 months (Cook *et al.*, 2005; Hacker, 1992). *Desmodium uncinatum* is less drought resistant compared to *D. intortum* (FAO, 1979). It is tolerant to shade (ILRI, 2013c), more so than *D. intortum* (FAO, 2013c).

Pueraria phaseoloides, native to tropical Asia, grows well under direct sunlight, and is moderately shade tolerant (Watson, 1963; Wong *et al.*, 1985). It is often grown as a cover crop in tree plantations in Southeast Asia (Blair *et al.*, 1986). *Pueraria phaseoloides* is not drought tolerant. However, it was reported that *P. phaseoloides* can survive short dry periods (Kannegieter, 1967). This drought susceptibility is a problem when grown under a tropical savanna climate with wet and dry seasons.

Chamaecrista rotundifolia, a short-lived perennial or self-regenerating annual herb, is reasonably drought tolerant (FAO, 2013e; Pengelly *et al.*, 1997). It requires full sunlight to moderate shade (Cook *et al.*, 2005).

Vicia villosa grows in areas with average annual rainfall of 350–1,000 mm. It is intolerant to drought at early stages of establishment but has a medium tolerance thereafter (FAO, 2013d). *Vicia villosa* has a poor to moderate shade tolerance (FAO, 2013d).

Vigna unguiculata is moderately adapted to shade, but in agroforestry or orchard applications shade should not be too heavy (Sheahan, 2012). *Vigna unguiculata* is well adapted to a wide precipitation range (650–2,000 mm), and is moderately tolerant to drought (Clark, 2007; Sheahan, 2012).

Arachis pintoi shows some drought-resistance once established (Fisher and Cruz, 1994). This species will survive in areas with an annual rainfall of 1,000 mm or less, but grows best with over 1,500 mm $year^{-1}$. *Arachis pintoi* survives dry seasons of up to 4 months. It is highly tolerant to shade, where it often appears more vigorous than in full sunlight (Fisher and Cruz, 1994; Cook *et al.*, 2005).

Heavy shade does not favour the initial growth of *Lablab purpureus*, but once established this species can continue to grow in shady conditions (Cook *et al.*, 2005; Sheahan, 2012). *Lablab purpureus* is drought tolerant once established (Luck, 1965), and will grow where rainfall is <500 mm, but loses leaves during prolonged dry periods. *Lablab pupureus* is more drought tolerant than other similar legumes, like common beans (*Phaseolus vulgaris*) and cowpea (Maass *et al.*, 2010), and can access soil water due to its deep taproot, even in heavy textured soils.

Macrotyloma axillare was reported as having an average to good drought tolerance (ILRI, 2013a; Baijukya, 2004; Morris, 2008; Mansfeld and Büttner, 2001), while having a moderate shade tolerance, making it an ideal cover crop for agroforestry systems under tree canopies (do Carmo Araújo *et al.*, 2017).

The current study was carried out to assess growth and yield traits of these ten selected forage legumes when grown intercropped with mature enset plants, to improve productivity per unit area and enhance biomass production and feed availability.

Materials and methods

Experimental sites

The performance of forage legumes integrated in mature enset fields and under sole-cropping was assessed at the Areka Research Centre of the Southern Agricultural Research Institute (SARI-Areka) during the period 2014 to 2016. The research centre is located at 7°09'N latitude and 37°47'E longitude, with an elevation range of 1,750 to 1,800 m above sea level (m a.s.l.) (Ethiopian Mapping Authority, 1988). The soil is of the silty loam type with a pH range of 4.8 to 5.6 and low to medium organic matter content (2.6–5.6%) (Abayneh, 2003). The average annual rainfall for the study period (2014–2016) was 1,539 mm, while minimum and maximum mean temperatures were 14.5 °C and 25.8 °C, respectively. Thus, weather conditions were favourable for vigorous/optimum growth and development of the enset crop.

The performance (growth and yield) of shade-tolerant forage legumes was also assessed in farmers' fields, using plots with 4–5 year old vigorously growing enset plants in the Lemo and Angacha districts of southern Ethiopia in 2015. No irrigation took place at the various trial sites. Manure and

Table 1. Assessed forage legume species according to planting date, trial location and assessment year. In addition, shade- and/or drought-tolerance level is reported.

Forage legume species	Common names	Shade-tolerance#	Drought-tolerance#	Trial locations / assessment years: Areka on station (inter-cropping)	Areka on station (sole-cropping)	Farmer fields in Lemo and Angacha	Planting date	Average plant density*
Centrosema pubescens	Centro or butterfly pea	Moderate	Tolerant, can survive dry season of 3–4 months	2015, 2016			July 2014	5 × 20 cm
Desmodium intortum	Green leaf	Good	Poor, susceptible to extended dry spells	2015, 2016			July 2014	5 × 20 cm
Desmodium uncinatum	Silver leaf	Very good	Very poor	2015, 2016			July 2014	5 × 20 cm
Pueraria phaseoloides	Tropical Kudzu	Moderate	Poor, but can survive short dry periods	2015, 2016			July 2014	5 × 20 cm
Desmodium intortum	Greenleaf	Good	Poor, susceptible to extended dry spells	2015, 2016	2015, 2016	2015	July 2015	5 × 20 cm
Lablab purpureus	Hyacinth bean, Lablab bean, field bean	Poor to moderate	Tolerant due to deep root system	2015	2015	2015	July 2015	5 × 20 cm
Chamaecrista rotundifolia	Roundleaf sensitive pea, roundleaf cassia	Poor to moderate	Poor to moderate	2015, 2016	2015, 2016	2015	July 2015	5 × 20 cm
Arachis pintoi	Pinto peanut	Moderate to excellent	Moderate to good	2015	2015	2015	July 2015	5 × 20 cm
Macrotyloma axillare	Perennial horse gram	Moderate	Average to good	2015, 2016	2015, 2016	2015	July 2015	5 × 20 cm
Vigna unguiculata	Cowpea	Moderate	Moderate	2015	2015	2015	July 2015	5 × 20 cm
Vicia villosa	Vetch	Poor to moderate	Intolerant at early growth stage, but moderate tolerance thereafter	2015	2015	2015	July 2015	5 × 20 cm

#: information mainly taken from FAO and ILRI forage legume factsheets, and Wikipedia.
* Average plant density at physiological maturity stage and after thinning which was carried out at one month after seed germination.

inorganic fertilizer were applied, respectively twice and once per year, during the rainy season months, at the Areka on-station trials. Dried-up enset leaves were used year-round as mulch at both the Areka and on-farm sites, while manure was applied year-round in farmers' fields.

Trial designs and data collection methods

In July 2014, a first set of 4 forage legumes (*C. pubescens*, *D. intortum*, *D. uncinatum* and *P. phaseoloides*) were planted intercropped with vigorously growing enset at the Areka Research Centre. The enset plant spacing between rows and plants was 1.5 by 1.5 meter and plants were 3 years old. At the time of first planting of forage legumes, the height of enset plants ranged from 0.5 to 2.5 meter, and overall shade level was 25–40%. Old dried-up enset leaves were regularly trimmed. The legumes were planted in 3 replicates, with a plot size of 4 m^2 for each legume species. The legumes were planted in rows, and planting density was 5 by 20 cm (Table 1). The legume fresh and dry above-ground biomass yield was assessed for 5 plants per legume species. The plants were assessed/collected at the centre of each plot, at the end of the rainy season (*i.e.*, in November) in 2015 and 2016. The forage legumes were not harvested and above-ground biomass, including grain, was left in place as mulch. Regrowth of all the four forage legumes was observed in two subsequent rainy seasons, and no replanting was carried out. This also provided information about the legume plant's ability to tolerate drought during a 7-month dry season.

In addition, and due to promising initial observations made on the first set of forage legumes planted in 2014, a second set of 7 forage legumes (*D. intortum*, *L. purpureus*, *C. rotundifolia*, *A. pintoi*, *M. axillare*, *V. unguiculata* and *V. villosa*) was planted under vigorously growing enset at Areka in July 2015. The enset plants were spaced at 1.5 by 1.5 meter and were 4 years old. Enset plant height ranged from 1 to 3 m, and overall shade level was 30–45%. Old dried-up enset leaves were regularly trimmed. The legumes were planted in 3 replicates, with each plot having an area of 4 m^2 (2 × 2 m). The legumes were planted in rows, and planting density of the legumes was 5 × 20 cm (Table 1).

The same 7 forage legumes (set 2) were also planted in July 2015 under sole-cropping at the Areka research station. Each legume sole-cropped plot measured 2.5 × 30 m. Detailed legume growth and yield traits in the July 2015 planted intercropped and sole-cropped fields were assessed in November 2015. The following legume plant growth/development parameters were assessed in a net plot (1 m^2) at the centre of each legume plot: planting date, germination date, germination rate (calculated as the number of plants germinated over the total number of seeds planted), flowering date (when 50% of plants in the net plot had flowered), pod formation date (when 50% of pods for plants in the net plot had been formed), and physiological maturity date (when 50% of plants in the net plots had pods that turned yellow).

For above-ground biomass and root nodule

Table 2. Mean above-ground fresh and dry biomass weight of several forage legume species intercropped with mature enset plants at Areka in 2014, and assessed in November 2015 and 2016.

Forage legume species	2015				2016			
	Fresh biomass weight		Dry biomass weight		Fresh biomass weight		Dry biomass weight	
	(g)	(t ha^{-1})	(g)	(t ha^{-1})	(g)	(t ha^{-1})	(g)	(t ha^{-1})
Centrosema pubescens	77 c	15.3 c	37 c	7.5 c	114 c	22.9 c	56 c	11.2 c
Desmodium intortum	41 a	8.1 a	19 a	3.8 a	61 a	12.2 a	29 a	5.7 a
Desmodium uncinatum	53 b	10.7 b	26 b	5.1 b	80 b	16.0 b	39 b	7.7 b
Pueraria phaseoloides	57 b	11.5 b	31 b	6.2 b	86 b	17.2 b	47 b	9.3 b
LSD	6.5	1.3	5.9	1.2	9.9	1.99	8.9	1.78
P	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Means in a column followed by the same letter are not significantly different from each other at 5% least significant difference (LSD).

assessment, 5 plants per legume species were assessed at flowering stage, in the centre of each legume plot, for the 2015 intercropped and sole-cropped trials at Areka. Roots were cut off from the above ground tissue, and fresh and dry weight of the above ground plant biomass were measured. The number of nodules on the roots, and functional (brown-red in colour)/non-functional (white/green in colour) nodules were assessed in order to get an idea of atmospheric nitrogen fixation levels.

After plant growth and yield assessments, the remaining forage legume plants were not harvested and above-ground biomass including grain was left in place as mulch. Vigorous regrowth of 3 out of the 7 forage legumes (*M. axillare*, *D. intortum* and *C. rotundifolia*) was observed during the subsequent rainy season in 2016 in both the inter- and sole-cropped trials at Areka, while no replanting was carried out. *Arachis pintoi* showed limited regrowth with low levels of above-ground biomass production and was no longer assessed in 2016. Only above-ground fresh and dry biomass weight was assessed in November 2016 in the inter- and sole-cropped fields at Areka.

An additional forage legume assessment was carried out in 2015 in farmers' mature enset fields (using the same 7 forage legume species) in the Lemo and Angacha districts. In Lemo, trials were established in July 2015 on 10 farms in 2 areas ("Kebeles") with 5 farms in each Kebele, while in Angacha, trials were established in July 2015 on 3 farms in one

Figure 1. Vigorously growing Silverleaf desmodium (*Desmodium uncinatum*) under enset shade at the Areka research station in the 2015 rainy season. Silverleaf (planted in 2014) grew vigorously during the 2015 rainy season due to the established roots and lower stem sections, which survived the prolonged dry season (Source: Guy Blomme).

Kebele. Each farm served as a replication. Enset plants were on average 4 to 5 years old, were spaced 2 x 2 m, and were on average 2–4 meter high. The overall shade level ranged from 45–60%. Old dried-up enset leaves were regularly trimmed by the farmers. The same legume planting arrangements were applied as for the Areka-based trials. Legume growth and yield data was collected in November 2015, and data collection methods were the same as for the Areka-based intercropped and sole-cropped trials.

Statistical analysis

Analysis of variance (ANOVA), separation of means at 5% least significant difference and correlation analysis were carried out using the GenStat V. 12 statistical software (VSN International Ltd., 2009).

Results and discussion

For the intercropping trial planted in 2014, *C. pubescens* had the highest above-ground biomass production in both assessment years (2015 and 2016), while *D. intortum* had the lowest value (Table 2). *Pueraria phaseoloides* had the second-best above-ground biomass values. Although nearly all above-ground plant biomass dried up, all 4 forage legume species survived the 2 extended dry periods (*i.e.*, from November 2014 till May 2015, and from November 2015 till May 2016), re-sprouted and grew vigorously during the subsequent cropping seasons (starting in June 2015 and June 2016, respectively) (Figure 1). Higher biomass values were recorded in 2016 (Table 2), and this could be due to an expanding set of established roots and lower stem sections (that did not dry up) which survived the dry season.

Macrotyloma axillare produced the highest biomass yield in the 2015 established Areka intercropped and sole-cropped trials (Table 3). In the on-farm intercropping trials, it had the second highest biomass production after *L. purpureus*. *Arachis pintoi* (Figure 2) and *D. intortum* consistently produced the lowest amount of above-ground biomass across the 3 trials. *Chamaecrista rotundifolia* produced average levels of above-ground biomass across the 3 trials, while *V. villosa* and *V. unguiculata* produced average to above average levels of biomass (Table 3).

Five out of the 7 forage legumes (set 2) assessed at Areka in 2015 produced higher fresh biomass weight values in the intercropped fields compared to the sole-cropped field. This could be explained by the limited shade levels (30–45%) provided by the enset leaf canopy and a possible positive effect of limited shade on legume plant growth. This is in line with, for example, Fisher and Cruz (1994) and Cook *et al.* (2005) who reported that *A. pintoi* is highly tolerant to shade, where it often appears more vigorous than in full sunlight.

TABLE 3. Mean plant development traits and above-ground fresh and dry biomass weight for several forage legume species grown on farm and at Areka under mature enset and as a sole-crop at Areka. The forage legumes were planted in July 2015 and assessed in the same year. Five plants per legume species and plot were assessed at flowering stage in the sole-cropped and intercropped trials at Areka and in the on farm trials. Development and biomass traits (^{y}): DTG: Days to germination; GP: Germination percentage (in %); DTF: Days to flowering; DPF: Days to pod formation; DPM: Days to physiological maturity; FBW: Fresh above ground biomass weight (in g); FBW (%IC *vs.* SC): % of fresh above-ground biomass weight in intercropped field compared to sole-cropped field (calculated for 5 plants); DBW: Dry above-ground biomass weight (in g); FBW ha^{-1}: Fresh above-ground biomass weight (in t ha^{-1}); DBW ha^{-1}: Dry above-ground biomass weight (in t ha^{-1}); NN: Nodule number per plant; NC: Predominant nodule colour.

Species	Plant development and biomass traits^y										
	DTG	GP	DTF	DPF	DPM	FBW (% IC *vs.* SC)	FBW ha^{-1}	DBW	DBW ha^{-1}	NN	NC
						Inter-cropping on farm					
Arachis pintoi	32.1	36.7	162.1	-	222.1	18.88 (110)	3.8	9.49	1.90	-	-
Chamaecrista rotundifolia	30.4	55.2	146.1	156.0	188.2	20.44 (97)	4.1	10.31	2.06	8.22	Brown-red
Desmodium intortum	6.1	91.7	164.0	173.4	200.4	18.41 (101)	3.7	9.90	1.98	7.22	Brown-red
Lablab purpureus	9.0	98.2	56.4	69.8	129.1	25.52 (88)	5.1	12.50	2.50	8.33	Brown-red/white
Macrotyloma axillare	15.1	64.3	162.1	169.2	197.1	24.64 (77)	4.9	11.89	2.38	11.44	Brown-red
Vicia villosa	6.2	96.2	54.4	81.6	120.2	19.52 (82)	3.9	9.28	1.86	17.11	Brown-red
Vigna unguiculata	8	91.6	56.4	69.8	121.2	23.94 (81)	4.8	11.40	2.28	10.89	Brown-red/white
LSD	0.542	14	1.004	1.416	0.662	3.393	0.68	1.944	0.39	3.105	
P	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.007	0.007	<.001	
						Inter-cropping Areka					
Arachis pintoi	32	29.3	162.0	-	220.0	23.40 (137)	4.7	10.97	2.19	12.44	-
Chamaecrista rotundifolia	31	15.3	146.0	156.0	185.0	31.40 (149)	6.3	15.20	3.04	9.33	Brown-red/green
Desmodium intortum	7	59.7	165.0	173.0	201.0	26.70 (147)	5.4	12.37	2.47	10.33	Brown-red
Lablab purpureus	10	100	66.0	85.0	126.0	27.00 (93)	5.4	12.92	2.58	11.67	White
Macrotyloma axillare	17	36.7	162.0	168.0	195	40.4 (126)	8.1	19.23	3.85	15.33	Brown-red/green
Vicia villosa	8	99.7	60.0	91.0	125.0	27.0 (114)	5.4	11.57	2.31	19.00	Brown-red
Vigna unguiculata	9	100	64.0	85.0	128.0	26.6 (90)	5.3	12.00	2.40	9.00	Green, white, brown-red
LSD		6.44	-	-	-	6.039	1.21	2.527	0.51	5.304	
P		<.001	-	-	-	<.001	<.001	<.001	<.001	0.009	
						Sole-cropping Areka					
Arachis pintoi	32	68.0	158.0	-	215.0	17.1	3.4	8.20	1.63	-	-
Chamaecrista rotundifolia	31	35.0	141.0	152.0	172.0	21.2	4.2	10.10	2.02	11.00	Brown-red
Desmodium intortum	7	75.0	163.0	170.0	191.0	18.2	3.6	8.40	1.68	9.00	Brown-red
Lablab purpureus	10	100	54.0	68.0	108.0	29.2	5.8	14.30	2.85	17.00	Brown-red
Macrotyloma axillare	17	67.0	158.0	164.0	180.0	32.2	6.4	15.90	3.17	18.00	Brown-red
Vicia villosa	8	100	53.0	80.0	103.0	23.7	4.7	11.30	2.26	21.00	Brown-red
Vigna unguiculata	9	100	54.0	68.0	110.0	29.5	5.9	14.00	2.79	14.00	Brown-red

FIGURE 2. The forage legume *Arachis pintoi* performed very poorly under shade (Source: Guy Blomme).

The percentage legume fresh biomass weight in intercropped farmers' fields compared to Areka sole-cropped values (Table 3) was lower compared to the percentage of fresh above-ground biomass weight in Areka intercropped fields compared to sole-cropped fields. This might be linked to the larger enset plants in farmers' fields and associated higher shade levels.

In general, the number of nodules per plant decreased with increasing shade levels (Table 3). The highest number of nodules was observed in the sole-cropped field at Areka (overall average of 15 nodules per plant) (Table 3). The lowest number of nodules was observed in the on-farm intercropped trials, which had the highest shade levels (45–60% shade) (overall average of 11 nodules per plant). As for the Areka intercropped fields (30–45% shade), an overall average of 12 nodules per plant was observed.

The number of nodules was negatively correlated with time to flowering, time to pod formation and time to physiological maturity (Table 4). However, no clear links were observed between number of nodules and above-ground biomass weight. Brown-red functional nodules were the dominant nodule type across all trials (Table 3). However, some white and white/green non-functional nodules were also observed in the on-farm intercropped and Areka intercropped trials, respectively. Shelton and Stür (1991) reported that nodulation in shaded legumes was adversely affected and nodule numbers declined with increasing shade intensity, which would confirm the field observations made in this study. It is unlikely that a higher organic matter content of the soil (due to, *e.g.*, enset leaf/debris mulch at the intercropping trials at Areka and on-farm; and farmyard manure at the on-farm intercropping trials) in the intercropped trials negatively affected nodule development. Nodule number and above-ground biomass weight of legumes seem to increase with increasing levels of organic matter. For example, Masefield (1965) assessed the effect of incorporation of organic matter on legume nodulation (number and weight) in pot trials. The addition of farmyard manure increased the number of nodules for peas (*Pisum sativum*), field beans (*Vicia faba*) and French beans (*Phaseolus vulgaris*). As the data on nodulation from this study are based on one cropping season, further multi-year and multi-location research on forage legume nodulation would be needed to confirm the current observations.

Similar correlation values between various plant development and yield traits were obtained for both the intercropped and sole-cropped trials (Table 4). There was a negative correlation between days to germination and germination percentage (Table 4), indicating that the legume species that germinated earlier had the highest germination percentage. In addition, there was a negative correlation between germination percentage on one hand and days to flowering, pod formation and physiological maturity on the other hand, indicating that poorly germinating species took longer to mature. For example, *A. pintoi* had a poor germination percentage in the intercropped trials and hence took long to mature (Table 3). High positive correlations were observed between days to flowering, days to pod formation and days to physiological maturity. Fresh and dry above-ground biomass weight were also highly correlated.

Only 3 forage legumes of the trials planted in 2015 (set 2) (*M. axillare*, *D. intortum* and *C. rotundifolia*) survived the extended dry season (November 2015 till May 2016) and grew vigorously during the 2016 rainy season (*i.e.*, June till October) (Table 5). It was observed that, although the above-ground biomass gradually decreases during the extended dry season, roots and lower stem sections of these 3 legumes re-sprouted at the onset of the rains in both the sole- and intercropped fields at Areka. The forage legume *M. axillare* is very promising, as it not only grew vigorously in both the sole-cropped and intercropped fields, but it also survived the extended dry season and quickly re-sprouted at the onset

TABLE 4. Correlations between time to germination, germination percentage, plant development traits, fresh and dry above-ground biomass yield and nodule number per plant for the intercropping trials at the Areka research farm and in farmer's fields (below the diagonal) and for the sole-cropped trial at Areka (above the diagonal). Development and biomass traits (^{y}): See Table 3.

Development and biomass traits^y	DTG	GP	DTF	DPF	DPM	FBW	DBW	NN
DTG	1	-0.89*	0.44	0.45	0.43	-0.10	-0.07	-0.29
GP	-0.71**	1	-0.78	-0.79	-0.78	0.37	0.34	0.54
DTF	0.46**	-0.61**	1	1.00***	1.00***	-0.34	-0.32	-0.54
DPF	0.45**	-0.59**	0.99**	1	0.99***	-0.39	-0.36	-0.51
DPM	0.46**	-0.60**	0.99**	0.99**	1	-0.37	-0.35	-0.60
FBW	0.13	-0.29	0.03	0.00	0.01	1	1.00***	0.62
DBW	0.17	-0.31	0.12	0.09	0.11	0.91**	1	0.63
NN	-0.21	0.12	-0.29*	-0.24*	-0.32**	0.23	0.12	1

***, ** and * were significant at $P<0.001$, $P<0.01$ and $P<0.05$, respectively.

Table 5. Mean above-ground fresh and dry biomass weight for several forage legume species grown at Areka under mature enset and as a sole-crop. The forage legumes were planted in 2015 and fields were assessed in 2016. Five plants (in 1 replication) per legume species were assessed at flowering stage in the sole-cropped plots at Areka, while five plants (in 3 replications) per legume type were assessed in the intercropped plots at Areka.

Forage legume species	Areka intercropped field				Areka sole-cropped field				Fresh biomass weight[x] (%)
	Fresh biomass weight		Dry biomass weight		Fresh biomass weight		Dry biomass weight		
	(g)	(t ha^{-1})	(g)	(t ha^{-1})	(g)	(t ha^{-1})	(g)	(t ha^{-1})	
Macrotyloma axillare	71 b	14.13 b	34 b	6.77 b	140.5	28.10	31.7	6.33	51
Desmodium intortum	55 a	11.00 a	25 a	5.05 a	76.0	15.20	23.8	4.76	72
Chamaecrista rotundifolia	51 a	10.13 a	23 a	4.56 a	30.2	6.03	11.5	2.29	169
LSD	14.60	2.92	5.50	1.11	-		-		
P	0.034	0.034	0.006	0.006	-		-		

[x]: Percentage of fresh biomass weight (in g) in intercropped field compared to sole-cropped field.

Table 6. Above-ground legume dry matter expressed as a percentage of that produced under full sunlight (control). Source: Congdon and Addison (2003).

Legume species	Control (full sunlight)	Shade		
		63%	76%	84%
Desmodium uncinatum	100	62.3	35.2	23.5
Centrosema pubescens	100	43.8	31.8	19.0
Pueraria phaseoloides	100	44.1	32.3	16.2
Desmodium intortum	100	46.9	18.7	14.1
Macrotyloma axillare	100	53.0	2.1	1.5
Chamaecrista rotundifolia	100	37.8	28.6	2.2
Arachis pintoi	100	32.5	20.9	23.3

Figure 3. Vigorously growing *Macrotyloma axillare* under sole-cropping at the Areka research station during the 2015 (above) and 2016 (below) rainy seasons (Source: Guy Blomme).

of the rains (Figure 3; Tables 3 and 5). In line with the current study, *M. axillare* was reported as having an average to good drought tolerance (ILRI, 2013a; Baijukya, 2004; Morris, 2008; Mansfeld and Büttner, 2001), while having a moderate shade-tolerance, making it an ideal cover crop for agroforestry systems under tree canopies (do Carmo Araújo *et al.*, 2017).

Although *C. rotundifolia* produced the lowest fresh biomass weight values in both the Areka intercropped and sole-cropped fields in 2016, plant growth was observed to be better under moderate shade levels in the intercropped fields compared to sole-cropped conditions (Table 5). The 3 legume species that re-sprouted and grew vigorously during the 2016 cropping season (Table 5) in the Areka intercropped and sole-cropped fields had far higher biomass values compared to the previous year (Table 3), and this could be due to the established roots and lower stem sections which survived the dry season. It would hence be advisable for enset farmers to not uproot the forage legumes during the dry season to ascertain enhanced biomass production in the subsequent year.

Congdon and Addison (2003) assessed the production of above-ground dry matter for 35 legume species, under 4 shade levels. The 6 forage legumes that survived the dry season through root and lower stem sections in the current study were reported by Congdon and Addison (2003) as having an above-ground biomass production of at least 44% under 63% shade compared to that produced under full sunlight (Table 6). The lower biomass values reported by Congdon and Addison (2003) for *C. rotundifolia* and *A. pintoi* also seem in line with observations made in the current study.

Generally, in this on-station and on-farm research, some forage legumes (*M. axillare, C. pubescens*, *P. phaseoloides,* *L. purpureus, C. rotundifolia, V. villosa and V. unguiculata*) produced moderate to high amounts of above-ground biomass under intercropping conditions. Some other forage legumes (*M. axillare, D. intortum, C. rotundifolia, C. pubescens, D. uncinatum* and *P. phaseoloides*) were able to survive the prolonged dry season and grew vigorously during the subsequent rainy season due to the established roots and lower stem sections which survived the dry season. As forage legume biomass yields gradually increased during consecutive growing seasons, it is advised not to uproot the legume plants at the end of the rainy season in case biomass is harvested for fodder or mulch.

Feedback received from farmers in the Lemo and Angacha districts indicated that *M. axillare* (highest recorded biomass yield) and *D. intortum* (lowest biomass yield) could be integrated into mature enset plots. This would suggest that farmer criteria for selecting forage legume species goes beyond biomass production level. While discussing trial results with farmers, they also indicated that various shade-tolerant weed species produce significant amounts of biomass in mature enset fields, biomass that is often used as fodder.

Way forward

Further multi-location and multi-year on farm evaluations of the most promising forage legume species and surveys to determine edible weed species currently growing in mature enset fields should be carried out. Additional research on promising edible weed species regarding above-ground biomass production under shade and feed quality is also needed.

Acknowledgments

We would like to thank the Directorate General for Development, Belgium, for funding this research through the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA). We would also like to acknowledge the financial contribution of the CGIAR Research Program on Roots, Tubers and Bananas and the CGIAR Fund Donors. We are also indebted to the Southern Agricultural Research Institute (SARI) and the Areka Agricultural Research Centre for hosting the study and timely provision of the germplasm as well as necessary services and facilities during the field study.

References

Abayneh, E. (2003). Soils of the Areka Agriculture Research Center. Technical Paper No. 77. (Unpublished).

Abebe, T. (2005). Diversity of homegarden agroforestry systems of Southern Ethiopia. Ph.D. thesis (Wageningen, The Netherlands: Wageningen University), 153 pp.

Amanullah, M.M., Somasundaram, E., Vaiyapuri, K., and Sathyamoorthi, K. (2007). Inter-cropping in cassava. Agric. Rev. *28*, 179–187.

Baijukya, F.P. (2004). Adapting to Change in Banana-based Farming Systems of Northwest Tanzania. Ph.D. thesis (Wageningen, The Netherlands: Wageningen University Pro. Eco. and Res. Cons.), 192 pp.

Blair, G.J., Ivory, D.A., and Evans, T.R. (1986). Forages in Southeast Asian and South Pacific Agriculture: Proceedings of an International Workshop, Cisarua, Indonesia, 19–23 August 1985, ACIAR Proceedings Series No. 12, 202 pp.

Brandt, S.A., Spring, A., Hiebsch, C., McCabe, J.T., Tabogie, E., Diro, M., Wolde-Michael, G., Yntiso, G., Shigeta, M., and Tesfaye, S. (1997). The "tree against hunger". Enset-based agricultural systems in Ethiopia (Washington DC, USA: American Association for the Advancement of Science), 66 pp.

Chakeredza, S., Hove, L., Akinnifesi, F.K., Franzel, S., Ajayi, O.C., and Sileshi, G. (2007). Managing fodder trees as a solution to human–livestock food conflicts and their contribution to income generation for smallholder farmers in southern Africa. Nat. Resour. Forum *31*, 286–296. https://doi.org/10.1111/j.1477-8947.2007.00160.x.

CIALCA. (2010). CIALCA Baseline Survey Report. Consortium for Improving Agriculture-based Livelihoods in Central Africa. 129 pp.

Clark, A. (ed.) (2007). Cowpeas: *Vigna unguiculata*. In Managing Cover Crops Profitably, 3rd edn. (College Park, MD: Sustainable Agriculture Research and Education), pp. 125–129.

Congdon, B., and Addison, H. (2003). Optimising nutrition for productive and sustainable farm forestry systems – pasture legumes under shade. A report for the RIRDC/ Land & Water Australia/ FWPRDC MDBC Joint Venture Agroforestry Program, 99 pp.

Cook, B.G. (1984). Tropical pastures in eucalypt forest near Gympie. Queensland Agr. J. *110*, 45–47.

Cook, B.G., Pengelly, B.C., Brown, S.D., Donnelly, J.L., Eagles, D.A., Franco, M.A. , Hanson, J., Mullen, B.F., Partridge, I.J., Peters, M., and Schultze-Kraft, R. (2005). Tropical Forages. (Brisbane, Australia: CSIRO, DPI&F (Qld.), CIAT and ILRI).

CSA (Central Statistical Agency) (2011). Agriculture in Figures, Key Findings of 2008/09–2010/11. Agricultural Samples Survey for All Sectors and Seasons, Ethiopia.

Dapaah, H.K., Asafu-Agyei, J.N., Ennin, S.A., and Yamoah, C. (2003). Yield stability of cassava, maize, soya bean and cowpea intercrops. J. Agric. Sci. *140*, 73–82. https://doi.org/10.1017/S0021859602002770.

Desta, H.Z., and Oba, G. (2004). Feed scarcity and livestock mortality in enset farming systems in the Bale highlands of Southern Ethiopia. Outlook Agric. *33*, 277–280. https://doi.org/10.5367/0000000042664792.

do Carmo Araújo, S.A., Oliveira da Silva, T., Silva Rocha, N., and Olício Ortêncio, M. (2017). Growing tropical forage legumes in full sun and silvo-pastoral systems. Acta Sci. Anim. Sci. *39*(1), 27–34. https://doi.org/10.4025/actascianimsci.v39i1.32537.

DSRP. (2005). Document de Stratégie de Réduction de la Pauvreté Province du Sud-Kivu, République Démocratique du Congo (Kinshasa: Ministère du Plan, Unité de Pilotage de Processus du DSRP). 96 pp.

Eriksen, F.I., and Whitney, A.S. (1982). Growth and nitrogen fixation of some tropical forage legumes as influenced by solar radiation regimes. Agron. J. *74*, 703–709. https://doi.org/10.2134/agronj1982.00021962007400040026x.

Ethiopian Mapping Authority. (1988). National Atlas of Ethiopia (1st edn.). (Addis Abeba, Ethiopia: Berehanena Selam Printing Press).

FAO. (1979). A Zambian Handbook of Pasture and Fodder Crops (Food and Agriculture Organization of the United Nations), 139 pp.

FAO. (2013a). *Centrosema pubescens* Benth. http://www.fao.org/ag/AGP/AGPC/doc/Gbase/data/pf000019.htm (accessed May 9, 2017).

FAO. (2013b). *Desmodium intortum* (Mill.) Urb. http://www.fao.org/ag/AGP/AGPC/doc/Gbase/data/pf000026.htm (accessed May 9, 2017).

FAO. (2013c). *Desmodium uncinatum* (Jacq.) DC. http://www.fao.org/ag/agp/agpc/doc/gbase/data/pf000030.htm (accessed May 11, 2017).

FAO. (2013d). *Vicia villosa* Roth. http://www.fao.org/ag/agp/agpc/doc/gbase/data/pf000506.htm (accessed May 9, 2017).

FAO. (2013e). *Chamaecrista rotundifolia* (Persoon) Greene. http://www.fao.org/ag/agp/agpc/doc/gbase/data/pf000516.htm (accessed May 9, 2017).

Fekadu, D. (1996). Potential of Enset (*Ensete ventricosum*) in Ruminant Nutrition in Ethiopia. M.Sc. thesis (Uppsala, Sweden: Swedish University of Agricultural Sciences).

Fekadu, D., and Ledin, I. (1997). Weight and chemical composition of plant parts of enset (*Ensete ventricosum*) and the intake and degradability of enset by cattle. Livest. Prod. Sci. *49*, 249–257. https://doi.org/10.1016/S0301-6226(97)00047-X.

Fisher, M.J., and Cruz, P. (1994). Some ecophysiological aspects of *Arachis pintoi*. In Biology and agronomy of forage Arachis, P.C. Kerridge, and B. Hardy, eds. (Cali, CO: Centro Internacional de Agricultura Tropical, CIAT Publication No. 240), p. 53–70.

Hacker, J.B. (1992). *Desmodium intortum* (Miller) Urban. Record from Proseabase. L. 't Mannetje, and R.M. Jones, eds. (Bogor, Indonesia: PROSEA Plant Resources of South-East Asia Foundation).

Heuzé, V., and Tran, G. (2016). Centro (*Centrosema* molle). Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://www.feedipedia.org/node/321 (accessed May 9, 2017).

Horrell, C.R. (1958). Herbage plants at Serere Experiment Station, Uganda, 1954–57, 2: Legumes. East Afr. Agric. J. *24*, 133–138. https://doi.org/10.1080/03670074.1958.11665195.

ILRI. (2013a). Axillaris (*Macrotyloma axillare*) for livestock feed on small-scale farms. ILRI Forage Factsheet. https://cgspace.cgiar.org/handle/10568/2366?show=full.

ILRI. (2013b). Greenleaf (*Desmodium intortum*) for livestock feed on small-scale farms. ILRI Forage Factsheet. https://cgspace.cgiar.org/handle/10568/2377?show=full.

ILRI. (2013c). Silverleaf (*Desmodium uncinatum* cv. Silverleaf) for livestock feed on small-scale farms. ILRI Forage Factsheet. https://cgspace.cgiar.org/handle/10568/2364?show=full.

Kannegieter, A. (1967). Zero cultivation and other methods of reclaiming Pueraria followed land for food crop cultivation in the forest zone of Ghana. Trop. Agric. Vol. CXXV N° 3 and 4.

Karin, Z., and Alemu, K. (1995). A Field Guide to Enset Landraces of North Omo, Ethiopia. FRP Technical Pamphlet No. 9 (Addis Ababa, Ethiopia: Farm).

Luck, P.E. (1965). *Dolichos lablab* – A valuable grazing crop. Queensland Agr. J., May, p. 308–309.

Maass, B.L., Knox, M.R., Venkatesha, S.C., Angessa, T.T., Ramme, S., and Pengelly, B.C. (2010). *Lablab purpureus* – a crop lost for Africa? Trop. Plant Biol. *3*(3), 123–135. https://doi.org/10.1007/s12042-010-9046-1.

Manidol, C. (1984). Pastures under coconut in Thailand. In Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. FFTC Book Series No. 25. (Taipei, Taiwan: ASPAC).

Mansfeld, R., and Büttner, R. (2001). Mansfeld's Encyclopedia of Agricultural and Horticultural Crops (except Ornamentals) (Berlin, Germany: Springer-Verlag).

Masefield, G.B. (1965). The effect of organic matter in soil on legume nodulation. Exp. Agr. *1*(2), 113–119. https://doi.org/10.1017/S0014479700018676.

Morris, J.B. (2008). *Macrotyloma axillare* and *M. uniflorum* descriptor analysis, anthocyanin indexes, and potential uses. Genet. Resour. Crop Evol. *55*, 5–8. https://doi.org/10.1007/s10722-007-9298-2.

Ng, K.F. (1990). Forage species for rubber plantations in Malaysia. In Forages for Plantation Crops, Proceedings of a Workshop, Sanur Beach, Bali, Indonesia, 27–29 June, 1990, H.M. Shelton, and W.W. Stür, eds., p. 49–53.

Nurfeta, A., Eik, L.O., Tolera, A., and Sundstøl, F. (2008a). Chemical composition and *in sacco* dry matter degradability of different morphological fractions of 10 enset (*Ensete ventricosum*) varieties. Anim. Feed Sci. Technol. *146*, 55–73. https://doi.org/10.1016/j.anifeedsci.2007.12.003.

Nurfeta, A., Tolera, A., Eik, L.O., and Sundstøl, F. (2008b). Feeding value of enset (*Ensete ventricosum*), *Desmodium intortum* hay and untreated or urea and calcium oxide treated wheat straw for sheep. J. Anim. Physiol. Anim. Nutr. *93*, 94–104. https://doi.org/10.1111/j.1439-0396.2007.00784.x.

Nyabyenda, P. (2006). Les Plantes Cultivées en Régions Tropicales d'Altitude d'Afrique (Gembloux. Belgium: Les Presses Agronomiques de Gembloux), p. 22–24.

Ostrowski, H. (1966). Tropical pastures for the Brisbane district. Qld. Agric. J. *92,* 106–116*.*

Parbery, D.P. (1967). Pasture and fodder crop plant introduction at Kimberley Research Station, W.A., 1963–64. Part I. Perennial Legumes Tech. Mem. 67/6. (CSIRO, Aust. Divn. Land Res.).

Pengelly, B.C., Maass, B.L., Thomas B.D., and Hacker, J.B. (1997). Origin of the world's collection of the tropical forage legume *Chamaecrista rotundifolia*. XVIII International Grassland Congress, 8–19 June 1997, Winnipeg, Manitoba, and Saskatoon, Saskatchewan, Canada *1*(1), 25–26.

Plucknett, D.L. (1979). Managing Pastures and Cattle under Coconuts (Westview, Boulder: Westview Tropical Agriculture Series), 364 pp.

Pushparajah, E. (1982). Legume cover crops as a source of nitrogen in plantation crops in the tropics. In Non-symbiotic Nitrogen Fixation and Organic Matter in the Tropics. Symposia Papers No. 1 (New Delhi: Twelfth ISSS Congress).

Schultze-Kraft, R., and Clements, R.J. (1990). Centrosema: Biology, Agronomy, and Utilization (CIAT, Technology & Engineering), 666 pp.

Sheahan, C.M. (2012). Plant guide for lablab (*Lablab purpureus*) (Cape May, NJ: USDA-Natural Resources Conservation Service, Cape May Plant Materials Center).

Shelton, H.M., and Stür, W.W. (1991). Forages for plantation crops. Proceedings of a workshop, Sanur Beach, Bali, Indonesia, 27–29 June 1990. ACIAR Proceedings No. 32, 168 pp.

Sileshi, G., Akinnifesi, F.K., Ajayi, O.C., Chakeredza, S., Kaonga, M., and Matakala, P.W. (2007). Contributions of agroforestry to ecosystem services in the Miombo eco-region of eastern and southern Africa. African J. Environ. Sci. Technol. *1*, 68–80.

Skerman, P.J., Cameroon, D.G., and Riveros, F. (1988). *Centrosema* spp. In Tropical Forage Legumes, 2nd edn. FOA Plant Production and Protection Series. No. 2, P.J. Skerman, ed. (Rome, Italy), p. 237–257.

Stanley, S. (1966). Ensete in Ethiopia Economy. Ethiop. Geogr. J. IV, p. 20–32.

Teitzel, J.K., and Chen Chin Peng (2016). *Centrosema pubescens* (PROSEA). http://uses.plantnet-project.org/en/Centrosema_pubescens_(PROSEA) (accessed May 9, 2017).

Tolera, A. (1990). Animal production and feed resource constraints in Welayta Sodo and the supplementary value of *Desmodium intortum*, *Stylosanthes guianensis* and *Macrotyloma axillare* when fed to growing sheep feeding on a basal diet of maize stover. M.Sc. thesis (Norway: Agricultural University of Norway).

VSN International Ltd. (2009). GenStat 12th edn. www.vsni.co.uk.

Watson, G.A. (1963). Cover plants in Malayan rubber plantation. World Crops *15*, 48–52.

Whiteman, P.C., Bohoquez, M., and Ranacou, E.N. (1974). Shading tolerance in four tropical pasture legume species. Proceedings 12th International Grassland Congress (Moscow), p. 402–405.

Wong, C.C. (1990). Shade tolerance of tropical forages: A review. In Forages for Plantation Crops, Proceedings of a Workshop, Sanur Beach, Bali, Indonesia, 27–29 June, 1990, H.M. Shelton and W.W. Stür, eds., p. 64–69.

Wong, C.C., Sharudin, M.A.M., and Rahim, H. (1985). Shade tolerance potential of some tropical forages for integration with plantations. 2. Legumes. MARDI Research Bulletin *13*, 249–269.

Yilma, T. (2001). Coffee-Ensete-livestock interaction for sustainable livelihood in the Sidama area of Southern Ethiopia. J. Agric. Trop. Subtrop. *102*, 119–131.

Zeberga, A., Yemataw, Z., Sinebo, W., and Musemil, S. (2014). On farm cultivar diversity of enset (*Ensete ventricosum* W.) in Southern Ethiopia. J. Agric. Dev. *4*(1), 62–85.

Zinsou, V., Wydra, K., Ahohuendo, B., and Hau, B. (2004). Effects of soil amendments, inter-cropping and planting time in combination on the severity of cassava bacterial blight and yield in two ecozones of West Africa. Plant Pathol. *53*, 585–595. https://doi.org/10.1111/j.0032-0862.2004.01056.x.

Received: Jan. 30, 2018
Accepted: Oct. 19, 2018