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PARTICIPATORY EVALUATION OF IMPROVED GRASSES AND FORAGE LEGUMES FOR SMALLHOLDER LIVESTOCK PRODUCTION IN CENTRAL AMERICA

By EDWIN GARCIA†, PABLO SILES†, LISA EASH‡, REIN VAN DER HOEK†, SEAN P. KEARNEY§, SEAN M. SMUKLER§ *and* STEVEN J. FONTE‡¶

†*International Center for Tropical Agriculture, Km 17 Recta Cali-Palmira, Apartado Aéreo 6713, Cali, Colombia,* ‡*Department of Soil and Crop Sciences, Colorado State University, 1170 Campus Delivery, Fort Collins, CO, 80523, USA and* §*Faculty of Land and Food Systems, University of British Columbia, 2357 Main Mall, Vancouver, BC, V6T 1Z4, Canada*

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SUMMARY

Smallholder livestock systems in Central America are typically based on pastures with traditional grasses and associated management practices, such as pasture burning and extensive grazing. With the rise of the global population and a corresponding increase in demand for meat and milk production, research efforts have focused on the development of improved grasses and the incorporation of legume species that can increase productivity and sustainability of Central American livestock systems. However, farmer adoption remains very limited, in part due to the lack of site-specific evaluation and recommendations by local institutions. Using a multi-site participatory approach, this study examined the potential of five improved grasses and five species of forage legumes as alternatives to the broadly disseminated grass *Hyparrhenia rufa* (cv. Jaragua) in pasture-based cattle systems in western Honduras and northern El Salvador. Improved grasses (four *Brachiaria* sp. and *Megathyrsus maximus*) produced significantly more biomass than *H. rufa*; also four of the five legume varieties evaluated (*Canavalia ensiformis*, *Canavalia brasiliensis*, *Vigna unguiculata*, and *Vigna radiata*) demonstrated high adaptability to diverse environmental conditions across sites. Farmer participatory evaluation offers a valuable means to assess performance of forages and will likely contribute to their improved utilization. Future research is needed on more refined management recommendations, pasture system design, costs and environmental benefits associated with the adoption of these forages in local livestock production systems.

INTRODUCTION

By the year 2050, growth in the global population and shifts in diet may require an associated 70% increase in global food production. Demand for meat (and to lesser extent for milk) is directly correlated with per capita real income, and is increasing at an even higher rate, particularly in developing nations (Tilman *et al.*, 2011). Current efforts have focused on the intensification of livestock systems in developed countries and greater land clearing (extensification) in developing nations. If this trend is to continue, an estimated one billion ha of land would need to be cleared globally by 2050, representing a 30% increase over current pasture area. This

¶Corresponding author. Email: Steven.Fonte@colostate.edu

number could be decreased to 0.2 billion ha if policy-makers and research efforts instead focus on moderate intensification of existing agricultural systems in under-yielding regions (Tilman *et al.*, 2011). Thus, transfer of high-yielding technologies to existing production areas may substantially reduce environmental impacts, while satisfying the global food demand.

Aside from providing 25% of protein consumed worldwide, appropriately managed livestock systems have been shown to support diverse ecosystem services, including water-flow regulation and erosion control, climate regulation as well as soil biodiversity conservation (Fisher *et al.*, 1994; Lavelle *et al.*, 2014; Montenegro *et al.*, 2016). However, a large portion of livestock systems are based on low-yielding forage crops and apply practices that contribute to environmental degradation and high greenhouse gas emissions (Herrero *et al.*, 2013). In Central America, pastures dominated by *Hyparrhenia rufa* (locally known as Jaragua) were introduced to Pacific parts of the region several decades ago and are typically managed with fire to stimulate regrowth at the end of the dry season. Pasture burning has been shown to contribute to soil degradation and when not closely monitored can impact forested areas that support a range of landscape level ecosystem services (Steinfeld *et al.*, 2006). Such pastures are widespread throughout the region and their relatively low biomass yields suggest considerable room for improvement. Given the pervasiveness of cattle production in Central America and globally, there is great potential for more productive forages and management practices to enhance sustainability of these regions (Rao *et al.*, 2015).

In the last 20 years, a number of improved grasses have been developed and made commercially available with the aim of increasing forage productivity (Argel *et al.*, 2007; Miles *et al.*, 2004; Pizarro *et al.*, 2013; Rao *et al.*, 2015). Many of these (e.g., *Brachiaria* sp.) are adapted to sub-optimal environments (i.e., pests, drought or waterlogging prone areas). Legumes have also been considered as potential forage crops, and in addition to their benefits, such as N-fixation and contribution to soil nutrient cycling, legumes also produce high quality feed. Similar to work on grasses, research efforts have focused on identifying and selecting legumes that are adapted to acidic soils with low to moderate fertility. Promising legumes include those in the genera *Vigna* and *Canavalia*. For instance, *Canavalia brasiliensis* performs well in areas with extended dry seasons (Peters *et al.*, 2010).

Despite the potential of these improved forages in tropical conditions, adoption by local producers has been limited. According to Rao *et al.* (2015), the main constraints to the adoption of legumes and grasses have been the susceptibility to diseases and pests, the lack of clear management recommendations, seed availability and unrealistic expectations of farmers for rapid and dramatic increases in production. Another possible limitation is that development organizations often view legumes solely as cover crops and green manure, when their potential uses as feed may be much more attractive to land managers (Douxchamps *et al.*, 2014; Kebede *et al.*, 2016). High spatial heterogeneity within and between farms can also act as a barrier to improved forage adoption by smallholders, since the optimal types and arrangements of grasses or legumes can vary widely depending on different niches within farms and landscapes, thus greatly complicating the selection process (Paul *et al.*, 2016).

The participation of local farmers in selection, adaptation and dissemination processes has been shown to increase the adoption of new innovations (Peters *et al.*, 2003; Pretty, 1995). Under this approach, farmers play an active role in the development of practices and contribute intimate knowledge of their farming systems as well as provide the social, economic and cultural context that often determines feasibility of adoption. A case study by Stür *et al.* (2002) in Southeast Asia emphasized the wide range of constraints, opportunities, and goals that are considered in farmer decision-making. Aside from high forage yields, farmers valued easy to cut herbage, fast regrowth after harvesting, low competition with adjacent crops, and ease of collection and transportation of plant material. Overall, farmers were more likely to adopt varieties that best met these locally valued criteria. In fact, Horne and Stür (1997) suggest that researchers may often focus on completely different forage evaluation criteria (e.g., live weight gain) than those that are the most valued by smallholders (e.g., risk management and labour constraints).

In this study, on-farm trials were conducted to evaluate the establishment and potential productivity of five improved grasses (with *H. rufa* as a control) and five forage legumes across seven different locations in the Dry Corridor of Central America (western Honduras and northern El Salvador), a region with a prolonged dry season that lasts five to six months. Results from the multi-site trials were combined with participatory evaluation by local producers and technicians to identify the most adapted and favourable cultivars in the region. Along with formal assessment of biomass production, diverse stakeholders were involved in a hands-on evaluation of improved grass and legume cultivars in order to understand the selection criteria that are of greatest concern to farmers and to identify the most viable options for adoption and scaling. We hypothesized that the improved grass options would outperform the widely distributed *H. rufa* across all sites, but that the best producing species and those mostly highly evaluated by farmers would vary according to the unique environmental contexts of each site. For legume species, we hypothesized that at least one species would perform well across local conditions and receive strong evaluations from participating farmers.

MATERIALS AND METHODS

Study site and experimental design

This study was carried out in a part of the Dry Corridor of Central America, specifically in the Chalatenango department in El Salvador and Lempira department in Honduras. Due to their close proximity (Supplementary Figure S1, available online at https://doi.org/ 10.1017/S0014479718000364), the sites share a similar climate and soil properties. Both areas are characterized by mountainous topography and annual crops and pastures dispersed throughout sub-humid tropical forest. Soils, generally shallow and rocky, are largely dominated by Entisols and Inceptisols (Fonte *et al.*, 2010; Kearney *et al.*, 2017). Average monthly temperature varies between

Table 1. Site locations and select soil characteristics for improved pasture and forage legume trials in El Salvador and Honduras.

Site	Experiment type	Coordinates	Elevation (m)	Slope (%)	Sand (%)	Clay (%)	pH	SOM (%)	P (ppm)	K (ppm)
Chalatenango, ES	Pasture	14° 2.40′ N 88° 57.92′ W	300	5	57.9	22.7	6.1	2.6	14	109.8
Comalapa, ES	Pasture	14° 7.46′ N 88° 58.17′ W	440	12	65.9	10.4	5.3	4.3	0.4	164.1
	Legume	14° 7.46′ N 88° 58.17′ W	442	15	64.2	11.4	5.3	3.7	0.4	101.6
Upatoro, ES	Pasture	14° 3.75′ N 88° 57.52′ W	360	10	55.0	16.4	5.3	7.5	0.4	86.4
	Legume	14° 3.73′ N 88° 45′ W	380	20	60.6	17.7	6.0	4.8	0.4	45.9
Isleta, Hn	Legume	14° 2.99′ N 88° 35.44′ W	400	30	64.7	18.2	5.5	3.2	8.0	72.7
San José, Hn	Pasture + Legume	14° 2.46′ N 88° 33.76′ W	280	15	65.1	18.8	5.3	2.7	2.3	122.7
San Lorenzo, Hn	Pasture + Legume	14° 3.50′ N 88° 35.18′ W	580	10	>55*	<20	5.4	2.7	7.8	42.9
Tenango, Hn	Pasture	14° 6.14′ N 88° 34.83′ W	870	35	66.2	12.4	4.7	4.0	0.9	94.6

*Soil texture evaluated by hand at this site, so precise numbers were not obtained.
Soil texture was determined by hydrometer method, pH using a ratio of soil to water of 2.5:1, soil organic matter (SOM) by Walkley and Black, and available P and K were evaluated using a Mehlich-3 extraction method.

22 and 27°C and average annual precipitation is 1500 mm, with at least 90% of rainfall occurring between May and November. Economic activity in both Lempira and Chalatenango is focused on agriculture, specifically maize (*Zea mays L.)*, sorghum (*Sorghum bicolor L.*) for grain and forage, and beans (*Phaseolus vulgaris L.*). Cattle production is becoming increasingly more important in the region, particularly in Chalatenango.

The study was conducted from August 2014 to October 2015 at seven research sites in the region, the majority of which contained both improved grass and legume trials (Table 1). The experimental sites were located on land of local cattle producers with interest in evaluating and planting the grass varieties and legume forage options. Five grasses were tested: *Brachiaria brizantha* CIAT 6780 (cv. Marandu), *B. brizantha* CIAT 26110 (cv. Toledo), *Brachiaria decumbens* CIAT 606 (cv. Basilisk), *Brachiara* hybrid (CIAT 36087; *B. ruziziensis* x *B. decumbens* x *B. brizantha* cv. Mulato II), *Megathyrsus maximus* CIAT 6962 (cv. Mombasa; previously known as *Panicum maximum*, cv. Mombasa). These were compared to *H. rufa* as a control since this is the most commonly grown grass species in the region and likely serves as a benchmark against which new grasses would be evaluated. Five species of legumes were also evaluated: *Canavalia ensiformis L.*, *C. brasiliensis* (CIAT 17009), *Vigna unguiculata* (cowpea), *Cajanus cajan* (pigeon pea) and *Vigna radiata* (mung bean) as supplementary protein fodder. Improved grasses and forage legumes were selected based on their performance at other sites with similar environmental conditions, farmer interest, and local seed availability (particularly in the case of legumes). All materials were tested using a randomized complete block design, with all treatments established in 4×4 m^2 plots, and each treatment present in four replicate blocks at each experimental site.

Grass plots were established in August 2014 under no-till management. Rows were spaced at 50 cm with 30 cm spacing between holes and five to eight seeds per hole. Fertilizer (43 kg N ha^{-1} and 23 kg P ha^{-1}) was applied in rows to the soil surface when plants were approximately 15 cm in height. Legumes were also established in August 2014, as per recommendations provided by Peters *et al.* (2010) and without fertilization. Briefly, *C. ensiformis* and *C. brasiliensis* were planted in rows spaced 50 cm apart and 30 cm spacing between holes and two seeds per hole. *V. unguiculata* and *V. radiata* were planted in rows spaced 50 cm apart with 20 cm between holes containing three seeds of *V. unguiculata* and 10 cm between holes containing three seeds of *V. radiata*. Rows of *C. cajan* were spaced at 1 m with 30 cm between holes, each containing 4 seeds.

Soil analyses

Baseline soils (0–20 cm) were sampled prior to the start of the experiment by collecting five sub-samples per site to form one composite sample for analysis. Upon collection, soils were air-dried and passed through a 2 mm sieve for analysis of soil texture (hydrometer method), pH using a ratio of soil to water of 2.5:1, soil organic matter (SOM; Walkley and Black), available phosphorus (P) and potassium (K) using Mehlich-3 extraction at the CENTA (Centro Nacional de Tecnología Agropecuaria y Forestal) laboratory in El Salvador.

Evaluation of forage and seed production

Biomass yield was measured at 90 days after planting (November 2014) for the grass trials at each of the seven sites to evaluate establishment. Grasses were cut to 15 cm from the soil surface in the entire plot, while a 2×2 m^2 sub-plot in the centre of each experimental plot was used for evaluation of biomass production to avoid edge effects. In order to assess the productivity and regrowth potential in the dry season, biomass production during the six month dry season was evaluated in two sites in Honduras (San Jose and Tenango) at the start of the wet season (May 2015). Additionally, a subset of the trials, three sites in Honduras and El Salvador, were re-evaluated at key time points in the subsequent wet season. In July and September of 2015, pastures at these three sites were uniformly cut and left to recuperate for approximately 60 days before sampling.

Biomass of the legumes was measured when 50% of the experimental plots had reached flowering stage at each site. Half of the plants from each plot were cut to the soil surface for estimation of biomass (with the exception of pigeon pea, which was cut to a height of 60 cm to allow for potential regrowth, a unique attribute of this species; Rusinamhodzi *et al.*, 2017). Dry biomass was determined for each species after oven-drying samples at 60 °C. The other half of each plot was left intact to determine days

Table 2. Criteria and importance levels defined by local producers to evaluate the quality of each evaluated species of grass or legume.

No.	Producer-identified criterion	Description	Importance (1–10)
1.	Growth	Refers to the observed volume of forage (height, volume and thickness). Greater volumes are associated with higher rankings.	10
2.	Coverage	Refers to soil cover of the forage species. More ground cover is associated with higher rankings.	10
3.	Colour	Refers to the colour of the foliage. A green-blue colour is ideal, while a yellow colour is undesirable.	8
4.	Lusciousness	Refers to scent and texture. Measured by rubbing a few leaves gently between fingers. Scent of corn with a soft texture is ideal.	5.5

to maturation and seed production potential. Seed yield was reported at a moisture content of 13%. These plots were not re-evaluated after the first harvest since not all of the species tested have the ability to regenerate successfully after cutting.

Participatory evaluation of forage materials

Approximately 60 days after planting, participatory workshops were held at three of the study sites, but involved cattle producers from all of the experimental sites. Producers first worked together with project staff to define a set of key criteria for assessing grasses and legume forage crops (Hernández, 2007). The four main criteria included: growth, soil cover, foliage colour (all estimated visually) and perceived palatability or lusciousness (assessed by smell and texture; Table 2). These criteria were then ranked by the producers (1–10) to develop a weight of the relative importance of each to be used in the final calculation of an overall score for each grass and legume material tested. Following this discussion, six groups of 3–4 producers were formed and asked to closely observe the materials growing in all of the replicate blocks at the experimental site. Each material (grasses and legumes) was then ranked on a scale of 1–5 for each criterion (1 – poor; 2 – fair; 3 – good; 4 – very good; 5 – excellent) and scores were tallied to provide an overall weighted measure of producer acceptance. The participatory evaluation carried out here sought not only to capture farmer perceptions of the genetic materials tested, but also to facilitate dissemination of these materials and engage in preliminary training of cattle producers and local technicians.

Data analysis

Comparison of dry biomass production for each trial and sampling time were analysed using ANOVA. Natural log transformations were applied as necessary (mainly for the grass production data) to meet the assumptions of ANOVA (i.e., normality, homogeneity of variance). A preliminary analysis was conducted in which data across sites were analysed together, with treatment considered a main effect and both sites and blocks treated as random variables. Significant interactions between site and treatment indicated that treatment effects were better evaluated on a site-by-site basis, with only forage species and block (treated as a random variable) included in the model for each site. Tukey's honest significant difference was used to determine differences between treatments. Results from participatory evaluations by local producers were analysed with a non-parametric Kruskal–Wallis test. All statistical analysis was carried out using the software INFOSTAT and significant differences reported at the $P < 0.05$ level.

RESULTS

Biomass production

At the first sampling, 90 days after planting, there was considerable variation in initial grass biomass production between sites; one site in particular (San Jose) presented the highest biomass production with twice the value observed at the other sites. Overall, *B. decumbens, M. maximus*, *B. brizantha* (Marandu) and *B. brizantha* (Toledo) generally produced more biomass than the *Brachiaria* hybrid (Mulato II) and *H. rufa* across all sites, although the most productive grass varied across sites (Table 3). For example, in both San Jose and San Lorenzo, Honduras, *B. decumbens* was the most productive, with more than four times higher biomass than *H. rufa*. In Tenango and Upatoro, *B. brizantha* (Toledo) was the most productive, having five times greater biomass than *H. rufa* at the Upatoro site. While in Comalapa and Chalatenango, El Salvador, *M. maximus* was the highest yielding grass cultivar, producing significantly more than *H. rufa* at both sites. While never being the most productive at any particular site, *B. brizantha* (Marandu) was consistently high yielding across all sites showing the highest stability value in biomass production during establishment.

The cumulative grass biomass production during the dry season, measured at the beginning of the wet season in May 2015, showed a dramatic decrease, considering that measurements represent production across a total of six months. This measurement in San Jose and in Tenango demonstrated a similar trend to that observed in the initial biomass measurement; *B. decumbens* produced three times more biomass than *H. rufa* in San Jose, and *B. brizantha* (Toledo) yielded the highest in Tenango (but was not significantly different from *B. brizantha* (Marandu), *M. maximus* or *B. decumbens*). While *B. decumbens* continued to produce the most biomass during the wet season in San Jose, significant differences were only encountered for the September 2015 sampling date. While all varieties continued to produce better than *H. rufa* in Comalapa and Upatoro during the July and September 2015 sampling dates, these differences were not significant (Table 3).

For the legumes, *C. ensiformis* and *C. brasiliensis* generally demonstrated the highest biomass production (except for the Isleta site in Honduras). *V. unguiculata* and *V. radiata* tended to produce less biomass, but reached their flowering stage in a much shorter period of time (Table 4). While biomass production of *C. cajan* was high in Upatoro, its yields were highly variable across sites, even failing to germinate in two sites. *C. ensiformis, C. brasiliensis* and *C. cajan* required about double the amount of time to reach flowering than did *V. unguiculata* and *V. radiata*. A comparison of biomass production on

Table 3. Mean forage production of six grasses at seven sites in Honduras and El Salvador.

Site	Species/Cultivar*	Nov. 2014[†]			May 2015			July 2015		Sept. 2015		
		Dry biomass (kg ha^{-1})										
San José, Hn	*B. decumbens*	10,225	a	*393*	4232	a	*620*	9118	*1034*	7072	a	*901*
	M. maximus	8224	ab	*700*	3912	a	*809*	8216	*823*	5789	ab	*429*
	B. brizantha (Mar)	7318	ab	*1044*	2886	ab	*354*	8268	*612*	5684	ab	*708*
	B. brizantha (Tol)	5739	bc	*915*	2147	ab	*676*	7798	*1342*	4886	ab	*916*
	B. hybrid	4344	bc	*1210*	2812	ab	*747*	7531	*682*	3895	ab	*596*
	H. rufa	1866	c	*219*	1221	b	*315*	5447	*1175*	3000	b	*1175*
		$P < 0.001$			$P = 0.010$			*Ns*		$P = 0.056$		
Tenango, Hn	*B. brizantha* (Tol)	2294	a	*279*	4816	a	*729*					
	B. brizantha (Mar)	1968	a	*274*	4088	a	*455*					
	M. maximus	1609	a	*172*	2554	a	*283*					
	B. decumbens	1420	a	*245*	3270	a	*458*					
	B. hybrid	590	b	*59*	1203	b	*151*					
	H. rufa	ng[c]										
		$P < 0.001$			$P < 0.001$							
San Lorenzo, Hn	*B. decumbens*	4346	a	*657*								
	M. maximus	3509	a	*1076*								
	B. brizantha (Mar)	3279	a	*649*								
	B. brizantha (Tol)	3015	ab	*728*								
	H. rufa	994	bc	*293*								
	B. hybrid	752	c	*58*								
		$P = 0.001$										
Comalapa, ES	*M. maximus*	4749	a	*917*				3873	*625*	2120		*180*
	B. brizantha (Mar)	3795	a	*402*				5311	*462*	2398		*156*
	B. decumbens	3043	ab	*675*				3333	*1217*	2310		*383*
	B. brizantha (Tol)	2904	ab	*513*				4601	*460*	1918		*120*
	B. hybrid	2890	ab	*566*				2969	*710*	1890		*276*
	H. rufa	1298	b	*423*				2458	*347*	1857		*250*
		$P = 0.005$						*ns*		*ns*		
Upatoro, ES	*B. brizantha* (Tol)	3124	a	*684*				2148	*417*	1640		*295*
	B. brizantha (Mar)	1809	ab	*250*				1291	*146*	1071		*180*
	B. decumbens	1330	b	*153*				1293	*259*	1094		*189*
	M. maximus	1089	b	*294*				1494	*52*	1517		*409*
	B. hybrid	607	b	*206*				1309	*375*	1115		*165*
	H. rufa	578	b	*235*				1309	*191*	1065		*113*
		$P < 0.001$						*ns*		*ns*		
Chalatenango, ES	*M. maximus*	5545	a	*2153*								
	B. brizantha (Mar)	3163	ab	*1037*								
	B. decumbens	2932	ab	*306*								
	B. brizantha (Tol)	1850	ab	*571*								
	B. hybrid	1548	ab	*243*								
	H. rufa	857	b	*355*								
		$P = 0.030$										

[a]Cultivar abbreviations: Mar, Marandu; Tol, Toledo; B. hybrid, *Brachiara* hybrid CIAT 36087.
[†]ng= Seed did not germinate.
Samples were cut at a height of 15 cm above soil surface on the following times: 90 days after planting (Nov 2014), just after the dry season (May 4–15, 2015) and during the wet season, after a ~ 60 day recovery period (July 13–24, 2015 and September 8–18, 2015). Values in italics to the right of each mean represent the standard error of the four blocks tested at each site. Means with a common letter are not significantly different according Tukey's Test. P-values for treatment comparisons at each site are presented below each set of means (ns, not significant at $P < 0.05$).

Table 4. Mean biomass production at flowering, days to maturity and seed production (kg ha^{-1}) of five species of legumes across five sites in Honduras and El Salvador.

Site	Species	Days to flowering*	Biomass at flowering (kg ha^{-1})			Rate of biomass gain (kg ha^{-1} day^{-1})			Time to maturity (days)†	Seed production (no. seeds per m^{-2})
San José, Hn	*C. ensiformis*	80	6354	a	*1347*	79.4		*16.8*	140	2591
	C. brasiliensis	102	5586	ab	*741*	54.8		*7.3*	150	336
	C. cajan	113	3843	ab	*1021*	34.0		*9.0*	nm	0
	V. unguiculata	44	1890	ab	*576*	42.9		*13.1*	55	1350
	V. radiata	44	1720	b	*494*	39.1		*11.2*	55	756
			P = 0.025			*ns*				
Isleta, Hn	*C. brasiliensis*	95	1781		*124*	18.8		*1.4*	nm	0
	C. ensiformis	95	1538		*534*	16.2		*5.6*	nm	0
	V. unguiculata	45	1207		*237*	26.8		*5.3*	55	856
	V. radiata	45	1065		*84*	23.7		*1.9*	55	711
	C. cajan	ng				*ns*				
			ns							
San Lorenzo, Hn	*C. brasiliensis*	92	2377	a	*353*	25.8		*3.8*	nm	0
	C. ensiformis	92	1975	a	*327*	21.5		*3.6*	nm	0
	V. radiata	45	693	b	*68*	15.4		*1.5*	55	471
	V. unguiculata	nse								
	C. cajan	ng								
			P = 0.001			*ns*				
Comalapa, ES	*C. ensiformis*	71	6006	a	*755*	84.6	a	*10.6*	162	1475
	C. brasiliensis	86	2999	ab	*449*	34.9	ab	*5.2*	162	138
	V. radiata	54	1266	bc	*570*	23.4	b	*10.6*	70	349
	V. unguiculata	57	1096	c	*477*	19.2	b	*8.4*	70	168
	C. cajan	94	350	c	*72*	3.8	c	*0.8*	nm	0
			P < 0.001			*P < 0.001*				
Upatoro, ES	*C. ensiformis*	91	4677	a	*449*	51.4		*4.9*	209	1985
	C. cajan	126	4497	a	*834*	35.7		*6.6*	215	91
	C. brasiliensis	112	2825	ab	*451*	25.2		*4.0*	nm	0
	V. unguiculata	55	1844	b	*446*	33.5		*8.1*	81	115
	V. radiata	44	1371	b	*530*	31.2		*12.0*	81	278
			P = 0.003			*ns*				

*ng= seed did not germinate; nse= was not established due to lack of seed.
†nm= did not mature within period of observation (220 days after planting).
Values in italics to the right of each mean represent the standard error of the four blocks tested at each site. Means with a common letter are not significantly different according Tukey's Test. P-values for treatment comparisons at each site are presented below each set of means (ns, not significant at $P < 0.05$).

a per day basis showed no significant difference between species, with the exception of *C. ensiformis* which in Comalapa was superior to all other species except *C. brasiliensis* (Table 4). *V. unguiculata* and *V. radiata* were the only species to produce seed in all sites in which they were established, while *C. ensiformis* produced seed in three of the sites, *C. brasiliensis* in two of the sites, and *C. cajan* produced seed only in Upatoro.

Participatory evaluation of materials

As a general trend, *B. decumbens*, *B. brizantha* (Marandú), *M. maximus* and *B. brizantha* (Toledo) were the pastures most favoured by local livestock producers (Table 5). The

Table 5. Participatory evaluation of forage materials at three farmer workshops.

	Grasses						Legume					
Site	Species*	Growth	Coverage	Color	Lusciousness†	Overall	Species	Growth	Coverage	Color	Lusciousness †	Overall
San José, Hn	*B. decumbens*	4.2 a	5.0 a	4.7 a	4.7	4.6 a	*V. unguiculata*	4.3 ab	4.8 a	4.3 a	4.3 ab	4.5 a
	B. brizantha (Mar)	3.5 ab	3.5 ab	4.0 abc	4.5	3.9 ab	*C. ensiformis*	4.7 a	4.2 a	4.5 a	3.0 c	4.0 ab
	M. maximus	4.7 a	3.0 b	3.0 c	3.8	3.7 b	*V. radiata*	3.5 bc	3.5 ab	3.2 b	3.7 abc	3.5 bc
	B. brizantha (Tol)	3.5 ab	3.3 b	3.7 bc	4.0	3.6 b	*C. cajan*	3.8 ab	1.7 c	3.8 ab	4.5 a	3.5 bc
	B. hybrid	2.2 bc	2.7 bc	4.3 ab	3.8	3.2 bc	*C. brasiliensis*	2.5 c	2.5 bc	3.2 b	3.3 bc	2.9 c
	H. rufa	1.3 c	1.3 c	3.2 bc	4.0	2.5 c		*P* = 0.003	*P* < 0.001	*P* = 0.016	*P* = 0.017	*P*= 0.001
		P < 0.001	*P* < 0.001	*P* = 0.005	*Ns*	*P* < 0.001						
Chalatenango, ES	*B. decumbens*	3.8 abc	4.4 a	4.1	3.9	4.0	*C. ensiformis*	5.0 a	5.0	5.0	3.9	4.7
	M. maximus	5.0 a	3.1 ab	3.4	3.6	3.8	*C. cajan*	5.0 a	3.1	4.7	4.1	4.2
	B. hybrid	3.4 bc	3.4 ab	4.1	4.2	3.8	*C. brasiliensis*	4.1 a	4.1	4.1	4.1	4.1
	B. brizantha (Mar)	4.1 ab	4.1 a	3.4	3.4	3.8	*V. unguiculata*	3.4 a	3.8	4.1	3.6	3.7
	B. brizantha (Tol)	4.1 ab	3.4 ab	3.4	3.4	3.6	*V. radiata*	3.8 a	3.8	3.1	3.1	3.5
	H. rufa	2.5 c	1.9 b	3.8	2.8	2.7		*P* = 0.04	*ns*	*ns*	*ns*	*ns*
		P = 0.002	*P* = 0.034	*ns*	*ns*	*ns*						
Comalapa, ES	*B.* hybrid	3.2 bc	3.9 a	4.7 a	4.5 a	4.0 a	*C. ensiformis*	4.8 a	4.8 a	4.8 a	3.8	4.5 a
	B. decumbens	3.5 b	4.3 a	4.2 ab	4.1 ab	4.0 a	*C. brasiliensis*	3.8 ab	4.0 a	4.3 ab	3.7	3.9 ab
	M. maximus	4.8 a	4.3 a	2.8 bc	3.7 bc	4.0 a	*V. unguiculata*	3.7 bc	3.5 ab	4.2 ab	4.0	3.8 ab
	B. brizantha (Mar)	4.0 ab	3.5 ab	4.2 ab	3.9 abc	3.9 a	*C. cajan*	3.7 bc	2.0 c	3.5 bc	4.2	3.3 bc
	B. brizantha (Tol)	4.0 ab	3.7 a	4.0 ab	3.3 c	3.8 a	*V. radiata*	2.5 c	2.5 c	1.8 c	2.8	2.4 c
	H. rufa	1.5 c	1.8 b	2.2 c	3.4 bc	2.2 b		*P* = 0.003	*P* < 0.001	*P* < 0.001	*ns*	*P* < 0.001
		P < 0.001	*P* = 0.018	*P* = 0.005	*P* = 0.009	*P* = 0.014						

*Mar, Marandu; Tol, Toledo; B. hybrid, *Brachiara* hybrid CIAT 36087.

†Average of scent and texture rankings.

Criteria defined and evaluated by farmers on a scale of 1 to 5, where 5 is the highest ranking. A weighted average was calculated taking into consideration the producer-determined weight or importance of each criterion. Means with a common letter are not significantly different. *P*-values for treatment comparisons at each site are presented below each set of means (ns, not significant at $P < 0.05$).

soil cover provided by *B. decumbens* was particularly desirable and the volume of biomass produced by *M. maximus* also received high rankings. Conversely, the *B.* hybrid (Mulato II) and *H. rufa* indicated low acceptance in terms of growth and soil cover and overall quality.

Examining the sites individually, *B. decumbens* was ranked the highest by producers at the San José (Honduras) site, predominantly due to its soil cover, growth, and colour. In Chalatenango, all species except *B. brizantha* (Toledo) scored higher than the native control *H. rufa*. *M. maximus* was favoured due to its rapid growth, while *B. decumbens* once again received high rankings due to the soil cover it provides. In Comalapa, all species received higher rankings than *H. rufa*, but none were clearly favoured by producers.

For the legumes tested, *C. ensiformis* was the highest ranked by producers across all sites, primarily due to its growth, soil cover and colour. *V. unguiculata* and *C. cajan* scored well among producers in terms of the perceived palatability (lusciousness). In San José, soil cover provided by *V. unguiculata* was also noted among farmers, being ranked as favourably as *C. ensiformis*. Similarly, in Comalapa *C. ensiformis* and *V. unguiculata* were favoured along with *C. brasiliensis* for all criteria. In Chalatenango, there was no significant difference between species, but *C. ensiformis* was rated higher on average than the other species.

DISCUSSION

Forage production and adaptability across experimental sites

The grasses evaluated in this study demonstrated establishment and early biomass production within the expected range for these species (Peters *et al.*, 2010; Pizarro *et al.*, 2013), thus suggesting that most of the improved materials were appropriately selected for the biophysical conditions studied here. Forage yields of improved varieties were generally higher than the *H. rufa* (Jaragua) control at the first sampling and in the dry season (at least for the two sites considered), but in the following wet season (July through September) this trend was less pronounced. This may be related to the short evaluation interval (~60 days) under lower than average rainfall conditions. The relatively low biomass production of the *Brachiaria* hybrid (Mulato II) was surprising and possibly due to the generally low soil fertility across all sites. Although Mulato II was developed to address low P availability and pH, as well as high aluminium toxicity (Argel *et al.*, 2005), the poor fertility of soils at these sites may be unique and related more to high sand content, than issues such as aluminium toxicity, but more research is needed. With the exception of Mulato II, all of the improved grasses evaluated in the study appear to be viable options for the replacement of *H. rufa* due to their high forage yields and general acceptance by local producers. Nonetheless, it is important to note that the pastures tested here were grown under recommended management techniques that are often not or inadequately applied by farmers due to lack of knowledge or resources, including labour.

The substantial variability observed in top performing forages across sites highlights the need to consider site-specific conditions when making pasture recommendations to cattle producers in the region. For example, *B. decumbens,* which demonstrated a great capacity for soil coverage and relatively high yields across all sites could be an appropriate choice on degraded soils or soils that are highly susceptible to erosion (Peters *et al.*, 2010; Shriar, 2007). Meanwhile, *M. maximus* (Mombasa) demonstrated a high growth potential and high forage yields in most sites, but should not be recommended for use in degraded soils or on steep slopes due to its relatively high nutrient demand and tendency to grow in bunches and thus provide poor soil cover (Hare *et al.*, 2015). Mulato II has been the grass most highly promoted in El Salvador by government institutions (possibly due to higher forage quality, including crude protein content), but was found in this study to be low yielding on sub-optimal soils and in the environmental conditions of Central America's Dry Corridor. In another study carried out in Africa involving different Brachiaria grasses, *B. brizantha* cv. Toledo and *B. decumbens* presented higher biomass production compared to Mulato II in low rainfall regions (Mutimura and Everson, 2012). Additionally, other trials established in the Dry Corridor in Nicaragua (not published data) suggest lower, or at best similar, performance of Mulato II compared to *B. brizantha* (Marandu and Toledo) or *M. maximus* (cv. Mombasa). When considering all grasses tested here, poor management and/or poorly adapted recommendations may explain, in part, the low adoption rates observed in the region and this clearly illustrates the importance of site-specific evaluation.

B. brizantha (Marandu and Toledo) were relatively productive across all sites and thus appear to be resilient to soils of varying fertility and environmental conditions. *B. brizantha* (Toledo) has also demonstrated relative tolerance to flooding (Cardoso *et al.*, 2014), which may explain its superior biomass production in Upatoro, where topography of the site and high organic matter content suggest seasonal waterlogging. Such resilience can contribute substantially to risk reduction and should therefore be considered in addition to productivity when making local recommendations. The use of more adaptable forages, along with their diversification in forage-based production systems reduces reliance on a single species that may be susceptible to particular abiotic stresses or host-specific diseases. It should, however, be noted that diversified systems are inherently more complex and require greater knowledge and/or labour to manage. Additionally, it should be noted that many of the grasses tested here typically grow for many years (Peters *et al.*, 2010) and results from this study may better reflect potential establishment and early production, rather than long-term productivity. While other participatory forage evaluations have noted the value of early growth in influencing adoption rates (Stür *et al.*, 2002), long-term productivity is essential for the success of forage cultivars and cannot be ignored. Still, a certain level of caution is warranted in extrapolating these results to a longer time interval.

Biomass yields of the legumes were also generally within the expected range and these species are therefore likely to be suitable for the study region. The *Canavalia* and *Vigna* species also demonstrated greater regional adaptability in their full development and capacity to produce seeds even in management conditions not suited for seed production (Peters *et al.*, 2010). This is an important consideration for forage types (e.g., legumes) with seeds that are particularly expensive or difficult to obtain from local markets. It is recommended to rotate *Vigna* spp. with other forage crops, such as maize or sorghum, as this genus is reportedly susceptible to common bean pests (Katunga *et al.*, 2014). We note that only one growth cycle for legumes was considered for data collection in this study. It is important to recognize that pigeon pea, for example, can provide several harvests per year and *C. brasiliensis* can regenerate three times during its biannual life cycle (Costa *et al.*, 2013; Douxchamps *et al.*, 2014). Taking into account multiple harvests per year would likely lead to added production benefits for farmers and therefore may increase the desirability of these legumes.

Implications and recommendations for scaling

The improvement of pasture management and genetic resources in the region would be an important advancement for the productivity and sustainability of livestock systems (Rao *et al.*, 2015). Based on the data provided here, incorporating improved grasses and legumes as forage crops could lead to a two- or three-fold increase in forage production per unit area, which allows for higher stocking rates, assuming adequate management. Many improved forage crops also have a higher nutritional quality, with protein contents up to double that of natural pastures (Kebede *et al.*, 2016; Peters *et al.*, 2010). Still, benefits extend beyond higher yields and improved nutritional content. Increased soil coverage associated with the improved pastures could help mitigate erosion, suppress weeds and contribute to C sequestration through the extensive root production associated with improved grasses (Fisher *et al.*, 1994; Lemaire *et al.*, 2014). Improved forages have also been shown to increase the nutritional balance of livestock feed and reduce methane emissions associated with cattle production (Montenegro *et al.*, 2016), while forage legumes in particular can contribute to soil fertility through the fixation of atmospheric N.

To achieve the full benefits of the improved pastures, a change in management practices must accompany the change in genetic material. This region is characterized by relatively low soil fertility and a prolonged dry season, thus grazing schemes should be designed through collaboration between producers and technicians and include rotational grazing to achieve greater efficiency of grazing areas (Peters *et al.*, 2003; Rouquette, 2015). This co-design of pasture systems also needs to consider climate change and the associated increase in drought intensity, as well as explore the suitability of multiple options (e.g., silage). Additionally, the moderate shade tolerance of improved grasses permits increasing tree density in pastures and the potential to obtain the additional benefits through implementation of agroforestry systems (Peri *et al.*, 2016).

The favourable response of farmers towards legume species should not be ignored in future efforts to improve livestock-based systems for meat and/or dairy production. While legume adoption as cover crops has not been as high as anticipated, legumes have a wide range of other uses that could provide additional economic benefit to farmers (Kebede *et al.*, 2016). For example, legumes could potentially be intercropped with annual crops or pastures, used for human consumption, planted in designated areas as protein banks for cut and carry management and also contribute to silage production (Costa *et al.*, 2013; Lima-Orozco *et al.*, 2016). Although ranked highly in both agronomic and participatory evaluations, some toxicity issues suggest that some caution should be exercised with the use of *C. ensiformis* as animal feed. To the contrary *C. brasiliensis* has been used as forage and green manure in smallholder crop-livestock system of the Nicaraguan hillsides. In these systems, *C. brasiliensis* is intercropped with maize and during the dry season the maize-*Canavalia* plots are grazed, allowing the animals to consume the maize stover and the green *C. brasiliensis* biomass (Douxchamps *et al.*, 2012). Silage could be of particular importance in this region since it is already a widely utilized in parts of the region and offers great potential to meet livestock needs during the dry season when high quality forage is scarce. However, the use of silage and/or cut-and-carry systems depends on the ability of land managers, especially smallholders, to protect land from grazing. More research is needed regarding the nutritional quality of legumes as fodder silage and costs of utilizing legumes vs. traditional maize silage (Reiber *et al.*, 2010). We suspect that improved familiarity of these legumes and efforts to better integrate them with a systems perspective could further improve perception of legumes and facilitate future adoption. We also note that increased focus on diary production, which typically has more frequent and faster revenue return than beef systems, could improve the ability of smallholders to invest in improved forages.

Participatory evaluation of pasture systems

This study emphasizes the importance of a participatory approach to establish more productive and sustainable livestock production systems in the region. Involvement of local producers informs the assessment of adaptability of new species while increasing the potential of adoption and impact (Horne and Stür, 1997; Peters *et al.*, 2003). The participatory methodology utilized in this study to evaluate forage species proved to be effective, as farmer response closely coincided with the agronomic data that were subsequently collected. Local input allowed the evaluation to extend beyond establishment and early biomass production, including farmers' criteria such as lusciousness and foliage colour. Farmer evaluations can differ from scientific findings. For example, when ranking perceived palatability (scent and texture), farmers favoured the *Brachiaria* hybrid (Mulato II), *B. brizantha* (Marandu), *B. decumbens, C. cajan* and *V. unguiculata*, while according to Peters *et al.* (2010) *B. decumbens* is not considered to have high palatability in Central America.

The involvement of farmers in the research process can lead to increased adoption of improved forages. Participating farmers have the opportunity to observe favourable attributes on their own land, such as improved soil coverage of *B. decumbens* and *C. ensiformis,* and are more likely to promote these materials amongst their neighbours. As a result, adoption of the improved pastures and legumes within the study area has been widespread following the completion of this research (Smukler *et al.*, 2017). While the findings presented here are encouraging, further experimentation (by farmers and researchers) is needed to better understand the role of inter-annual variability in driving the performance of these improved forage options.

CONCLUSIONS

In the face of rising demand for animal products, sustainability and productivity of smallholder livestock systems must be increased. Four of the five improved grasses – *B. brizantha* (cv. Marandu), *B. brizantha* (cv. Toledo), *B. decumbens* (cv. Basilisk) and *M. maximus* (cv. Mombasa) – exhibited high production potential and could therefore be considered viable replacements for traditional pastures, (i.e., *H. rufa,* cv. Jaragua). This suggests important benefits for forage production as well as soil conservation efforts, since *H. rufa* is typically burned annually and has poor soil cover at the onset of the rainy season. Forage legumes, specifically of the genera *Canavalia* and *Vigna*, also showed high regional adaptability. The multiple uses of these forages and their favourable response by farmers should help to inform future research efforts regarding their incorporation into livestock systems. In this study, participatory evaluation appears to be an effective approach for evaluating the performance and potential for adoption of forage crops across sites. This is supported by the fact that farmer evaluations largely agreed with the observed biomass production and their perceptions of forage quality (i.e., lusciousness) will likely be an important factor driving adoption. The materials evaluated here show a great potential for diffusion throughout Central America and similar regions, but additional studies are needed to better understand how inter-annual variability and environmental differences across sites affect not only biomass production, but also the nutritional value of the forage produced. Future research and dissemination efforts should seek to promote optimal management practices and explore the co-design of pasture systems together with researchers, technicians and local land managers. This approach would better facilitate the development and adoption of locally adapted pastures that contribute to the long-term sustainability of tropical livestock systems.

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SUPPLEMENTARY MATERIAL

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