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Research Paper

Evaluation of herbaceous legumes for crop-livestock systems in eastern Indonesia

Evaluación de leguminosas herbáceas para sistemas cultivos-ganadería en el este de Indonesia

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Abstract

The sale of cattle presents a significant opportunity to improve livelihoods for smallholder farmers in eastern Indonesia. An opportunity was identified to grow herbaceous forage legumes either in rotation with, or sown within, staple grain crops (maize, rice) to use surplus soil moisture to produce a feed bank for (mostly penned) cattle and potentially increase nitrogen supply to the grain crops. A series of experiments was conducted on Vertisol, Alfisol and Inceptisol soils in lowland and upland districts of eastern Indonesia to identify legumes from 18 taxa suitable for integrated crop-forage systems. *Clitoria ternatea* and *Centrosema pascuorum* were found to have best potential for these systems as they established reliably using local methods, consistently ranked highly for herbage yields 2–4 months after sowing and were relatively easy to harvest. Yields were highest on the Vertisol (greatest number of sites) and Inceptisol soils. *Lablab purpureus*, *Macroptilium bracteatum* and *Mucuna pruriens* also ranked high for yield on Vertisol soils. *Clitoria ternatea* regrew consistently after cutting and forage removal providing potential for extended forage production as growing conditions allow.

Keywords: Cattle, centro, clitoria, forage.

Resumen

La venta de ganado representa una oportunidad importante para mejorar los medios de vida de los pequeños agricultores en el este de Indonesia. Se identificó una oportunidad para cultivar leguminosas forrajeras herbáceas en rotación con, o sembradas en asocio, con cereales (maíz, arroz), para utilizar la humedad excedente del suelo para producir un banco de alimento para el ganado (en su mayoría estabulados) y potencialmente aumentar el suministro de nitrógeno a los cultivos de cereales. Se realizó una serie de experimentos en suelos Vertisol, Alfisol e Inceptisol en distritos de tierras bajas y altas del este de Indonesia para identificar leguminosas de 18 taxones adecuadas para sistemas integrados de cultivos y forrajes. Se encontró que *Clitoria ternatea* y *Centrosema pascuorum* tenían el mejor potencial para estos sistemas, ya que

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se establecieron de manera confiable utilizando métodos locales, ocuparon un lugar destacado en cuanto a rendimiento de forraje de 2 a 4 meses después de la siembra y fueron relativamente fáciles de cosechar. Los rendimientos fueron más altos en los Vertisoles (mayor número de sitios) e Inceptisoles. *Lablab purpureus*, *Macroptilium bracteatum* y *Mucuna pruriens* también obtuvieron una alta calificación en cuanto a rendimiento en Vertisoles. *Clitoria ternatea* fue consistente en rebrotar después del corte y la extracción del forraje, lo que brinda potencial para una producción prolongada de forraje cuando se presentan condiciones adecuadas para su crecimiento.

Palabras clave: Centrosema, clitoria, forraje, ganado.

Introduction

In many tropical countries, including Indonesia, the low yield and poor nutritive value of forages limits the productivity of cattle and other ruminants. Legumes have a demonstrated capacity to improve animal productivity in the tropics through the provision of high-quality feed (particularly digestible protein) while increasing the level of plant available nitrogen in soil for companion forages through symbiotic nitrogen fixation (Mannetje 1997). Herbaceous forage legumes present an opportunity to produce high quality forage for livestock through integration within cropping systems (multi-purpose system).

Cattle are a key live export for farmers in the East Nusa Tenggara [(Nusa Tengarra Timur (NTT)] province of eastern Indonesia. Cattle production was historically low and cattle mostly grazed on native grasslands (*Bothriochloa*, *Heteropogon*, *Themeda*) with only short-term nutritive value and productivity limited by extended dry periods (Ayre-Smith 1991; Piggin et al. 1991).

The integration of herbaceous forages directly into cropping systems could significantly increase cattle production within NTT and benefit resource-poor farmers in eastern Indonesia through the provision of affordable high quality fresh or conserved feed for ruminants. For success, herbaceous forage legumes ideally need to integrate simply and easily into mixed crop and livestock systems.

The testing of herbaceous and shrub forage legumes in NTT commenced on the island of Sumba (Nulik 1987) and on West Timor during the early 1980s (Piggin et al. 1987; Piggin et al. 1991). Both evaluations targeted legumes considered to have potential for introduction into native grass pastures, but demonstrated the potential for *Aeschynomene*, *Chamaecrista rotundifolia* (formerly *Cassia*), *Centrosema*, *Clitoria*, *Lablab*, *Macroptilium*, *Macrotyloma*, *Neonotonia*, *Stylosanthes* and *Vigna*.

In collaborative Indonesian-Australian research (2006–2017), plant evaluation was undertaken to identify herbaceous legumes likely to fit into crop-livestock farming systems in NTT (Bell et al. 2020; Dalgliesh et al. 2014). Legumes were sought for growth principally within maize (the principal dry-land crop) systems, either in rotation (sown on the same area but in sequence with the maize crop) or as a relay (sown into the maize crop with forage harvested after the maize harvest). This followed the measurement of surplus soil moisture after traditional maize crops had been harvested, presenting a potential resource for forage production (Budisantoso et al. 2008; Dalgliesh et al. 2010). The aim was to produce fresh forage for direct use in the early dry season or stored hay to supplement other low quality forage resources at other times of the year. As legumes in these systems would need to be resown regularly, ease of seed production and harvest was also sought to better enable uptake by farmers. The research was completed on 3 islands in NTT (West Timor, Flores and Sumba) to ensure wide adaptability of the target species.

This aim of this paper is to report consolidated results of field trials conducted in NTT over 10 years of collaborative research to identify legumes suitable for maize/rice-livestock systems in a range of environments in eastern Indonesia.

Materials and Methods

Experimental design, forages and locations

The study was a multi-site assessment of tropical forage legumes using plant biomass as the key indicator of plant performance under a range of growing environments in eastern Indonesia. Sixteen experiments lasting 1- or 2-years were used to evaluate legume productivity at 14 locations in 3 islands within the NTT province (Figure 1, Table 1). Experimental sites were either on-farm (12), at a government research station (Naibonat) or at an agricultural college (Soe). Soils at the sites comprised Alfisol, Inceptosol and Vertisol (Soil Survey Staff 1999) with elevations from near sea level to 900 masl, within a narrow latitude range from 8.4-10.1 °S (Table 1). The soils are of marine origin on West Timor and Sumba and volcanic origin on Flores. They represent a range in production capacity: Alfisols - erodible alkaline and typically low in organic carbon and key nutrients including nitrogen, phosphorous and potassium and low water holding capacity; Inceptisols - heavy alkaline clays of moderate fertility and water holding capacity; Vertisols - very heavy, cracking alkaline clay soils of moderate fertility and high water holding capacity (Dalgliesh et al. 2014). All of the soils selected are used for cropping. All the on-farm sites were located on mixed enterprise farms including crop (maize or rice) and cattle production. Each site and sowing year combination was treated as a separate experiment. Legume accessions were grown individually in small plots using a randomised complete block design with 2, 3 or 4 replicates per site (Table 1).

A total of 34 legume lines were tested with up to 17 assessed at an individual site. The legumes were mostly herbaceous, with either twining/trailing (*Centrosema*, *Clitoria*, *Lablab*, *Macroptilium*, *Mucuna*, *Vigna*), non-twining (*Alysicarpus*, *Arachis*) or sub-shrub (*Desmanthus*, *Stylosanthes*) growth habits. They were mostly Australian cultivars used for long and short-term pastures or conserved fodder production with similar soils and climate to the study area.

The experiments were completed over 10 years beginning in 2006. The assessments were initially completed on West Timor, where a broad range of taxa were tested at 6 sites during the 2006/07 season. More detailed appraisal on West Timor during 2010 and 2011 focussed on promising species from the previous studies, including additional cultivars within these species as well as some more recently commercialised cultivars representing new taxa to Indonesia. Plant evaluation was extended to the islands of Flores and Sumba in 2011 and 2016, respectively, focussing on lines which performed well on West Timor under similar growing environments. The exception was an upland site with a shallow Alfisol soil on Sumba (Milpinga), where a range of *Desmanthus* and *Stylosanthes seabrana* were tested in addition to the higher-performing lines tested from West Timor.

Figure 1. Locations of field sites used to test the growth of selected tropical forage legumes in eastern Indonesia, 2006–2017.

Table 1. Experimental site characteristics, management and biomass sampling.

Location	Site characteristics			Timetable of key experimental events			Experimental design and sowing rate		
	Coordinates °S, °E	Soil type	Elevation (m)	Sowing date	Cut-back date[1]	Biomass sampling dates	Plot size (m × m)	Replicates	Plant spacing (cm × cm)
West Timor									
Naibonat	10.08, 123.86	Vertisol	50	23 Mar. 2006	22 May	23 Mar., 20 Apr., 5, 18 May, 15 Jun., 12 Jul., 28 Aug.	6 × 10	3	Broadcast[3]
Biloto	9.87, 124.22	Inceptisol	560	18 Feb. 2007	NA	3, 16, 29 Mar., 13, 27 Apr., 23 May, 18 Jul., 3 Sep.	1 × 1	3	40 × 20
Kletek	9.58, 124.93	Inceptisol	70	28 Mar. 2007	NA	11, 26 Apr., 11, 25 May, 7, 20 Jun., 30 Aug., 19 Oct.	1 × 1	3	40 × 20
Kakanuik	9.58, 124.84	Inceptisol	48	12 Apr. 2007	NA	26 Apr., 11, 25 May, 7, 21 Jun., 10 Jul., 30 Aug., 7 Nov.	1 × 1	3	40 × 20
Sillu	10.05, 123.96	Alfisol	440	16 Feb. 2007	NA	2, 16, 29 Mar., 13, 28 Apr., 3 May, 18 Jul., 4 Sep.	1 × 1	3	40 × 20
Usapininot	9.45, 124.54	Inceptisol	360	14 Feb. 2007	NA	28 Feb., 14, 28 Mar., 12, 27 Apr., 9 May, 17 Jul., 30 Aug., 7 Nov.	1 × 1	3	40 × 20
Naibonat	10.08, 123.86	Vertisol	50	12 Mar. 2010	11 Jan.	12 May, 14 Jul., 15 Oct. 4 May, 3 Jul.	8 × 3	3	50 × 10
Naibonat	10.08, 123.86	Vertisol	50	22 Feb. 2011	NA	4 May, 4 Jul.	8 × 4	3	20 × 20
Soe	9.86, 124.26	Alfisol	900	27 Mar. 2010	NA	29 May, 29 Jul.	5 × 2	2	50 × 10
Flores									
Marapokot	8.53, 121.31	Vertisol	15	22 Feb. 2011	19 Apr., 14 Jun.	19 Apr., 14 Jun., 9 Aug.[2]	5 × 10[3]	3	20 × 20
Nakuramba	8.75, 121.58	Inceptisol	380	24 Feb. 2011	21 Apr., 14 Jun.	21 Apr., 14 Jun., 11 Aug.			20 × 20
Ulupulu	8.72, 121.32	Inceptisol	530	22 Feb. 2011	19 Apr., 14 Jun.	19 Apr., 14 Jun., 9 Aug.			20 × 20
Wolomasi	8.77, 121.73	Vertisol	715	25 Feb. 2011	22 Apr., 14 Jun.	22 Apr., 14 Jun., 12 Aug.			20 × 20
Ranokolo	8.46, 121.70	Vertisol	300	21 Feb. 2017	16 May	16 May, 8 Aug.	4 × 2	4	20 × 20
Sumba									
Milpinga	9.79, 120.34	Alfisol	240	23 Jan. 2016	28 Apr.	28 Apr.[2]	4 × 2	4	Rows 30 cm[4]
Wangga	9.68, 120.26	Vertisol	85	22 Jan. 2016	27 Apr.	27 Apr, 3 Aug.			Rows 30 cm[4]

[1] Whole plots were cut back to 5–10 cm after biomass sampling.

[2] Plots failed to regrow after cutting due to inadequate soil moisture so not sampled after cutting.

[3] Sowing rates: 5–7 kg scarified uncoated seed/ha or 6–12 kg coated seed/ha. This site was fertilised with 15.7% P, 5% Sulphur broadcast at 50 kg/ha on 12 April.

[4] Sowing rates: *Desmanthus* and *Stylosanthes* 10 kg/ha, *Centrosema* 12 kg/ha, *Clitoria* and *Vigna* 15 kg/ha and *Lablab* 25 kg/ha.

Climate

The climate of the study area can be considered semi-arid tropical with a dominant wet season and an extended dry season of 5–7 months. Rainfall patterns for most of the study areas were poorly described prior to the study, but broadly represent annual rainfall between 800 and 1,200 mm with lower values on Sumba and higher values on Flores. Highest rainfall occurs from November–March, but is potentially bi-modal on the southern coast of West Timor (Dalgliesh et al. 2014). Rainfall data were collected using automated tipping bucket and logging equipment, along with continuous temperature measurements (Table 2). A limited number of weather stations meant rainfall was occasionally not measured at a particular site, but nearby within the region. The equipment was mostly reliable, although equipment failure occasionally resulted in incomplete rainfall records. Rainfall was summer dominant at all sites with significant rainfall prior to sowing in January to March and more than 200 mm in the months after sowing at most sites. Exceptions were Naibonat (lowland) during 2010 and Usapininot (midland) during 2007 (both on West Timor), where sowing was followed by little rainfall between April and October. Rainfall was low overall at the sites on Sumba, with an extended dry season. Relatively high dry-season rainfall totals were recorded at Kakanuik (lowland, West Timor) and Nakuramba (middle elevation, Flores), with moderate (40–70 mm per month) rainfall recorded at Soe (upland, West Timor). The dry season rainfall at Soe coincided with extended periods of low radiation (data not presented) believed to have contributed to poor plant growth. Temperature records collected at sites on West Timor showed mean minima ranging from 16–24 °C depending on elevation and time of year and maxima ranging from 25–36 °C (Dalgliesh et al. 2014). These temperatures tend to be moderated during winter months and with elevation (Central Bureau of Statistics 2019).

Table 2. Rainfall (mm/month) at the legume assessment sites. Month of sowing in bold. Less reliable data in italics.

Island, District	Site	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
West Timor, Kupang	Naibonat	2006	533	185	**284**	33	2	3	0	0	6	51	89	276
	Naibonat	2010	261	191	**146**	81	15	34	1	1	0	0	63	302
	Naibonat	2011	500	453	256	455	66	0	3	0	0	66	228	257
	Sillu	2007	279	**192**	120	91	17	40	9	3	0	28	42	77
West Timor, TTS	Biloto	2007	204	**313**	191	0	3	0	0	0	0	0	19	353
	Soe	2010		170	**128**	236	337	40	48	48	73	206	299	131
West Timor, Belu	Kakaniuk	2007	81	129	376	**71**	45	455	49	122	1	4	34	159
	Kletek[1]	2007	*81*	*129*	***376***	*71*	*45*	*455*	*49*	*122*	*1*	*4*	*34*	*159*
West Timor, TTU	Usapinonot	2007	57	**148**	91	15	2	57	0	5	0	2	8	34
Flores, Ende	Wolomasi[3]	2011	284	**247**	334	289	98	22	F[4]					
	Nakuramba	2011	-	**213**	174	122	194	45	76	269	235	180	217	256
	Ranokolo	2017	*107*	***38***	*36*F[4]									
Sumba, Waingapu	Wangga[2]	2016	***123***	*149*	*150*	*28*	*31*	*40*	*9*	*18*	*4*	*76*	*5*	*123*
	Milipinga	2016	**123**	149	150	28	31	40	9	18	4	76	5	123

[1] Measured at Kakaniuk, ~10 km away

[2] Measured at Milipinga, ~13 km away

[3] Measured at Wolomasi, ~35 km away

[4] F=failure of rainfall logger

Experimental procedures

Each site was fenced to exclude grazing animals and cultivated manually or by using powered machinery (tractor and discs) to kill plants from previous cropping and prepare a relatively level site with a weed-free and friable seed bed. Any remaining weeds were controlled by hand-weeding or herbicide application (knapsack, glyphosate at label rates). The chosen sowing times and plant populations were those considered suitable for growing herbaceous legumes in eastern Indonesia based on researcher and farmer experience at the time.

Seeds for planting were mostly sourced from Australia and tested (water, 20/35 °C for up to 10 days) for germination to adjust sowing rates. Seeds of some lines were sourced within Indonesia in the latter stages of the study. Seed lots with high levels of hard seed dormancy were manually scarified using sand paper prior to sowing. Seed lots were inoculated in the first round of experiments (2006–07) with commercial *Bradyrhizobium* bacterial inoculum sourced from Australia, but not thereafter because farmers in this region are unlikely to have access to inoculum.

Seeds were sown by either ‘dibbling’ (directly into small holes made with a pole (dibble stick) and covering with soil) (most sites), sowing into shallow furrows or broadcasting by hand onto the soil surface and covering seed with soil using a rake (Table 3). Two to 5 seeds (fewer for large seeded taxa) were sown per dibble hole to ensure good establishment, and a range of spacing configurations used (20 or 25 holes/m^2). Seedling plants were not thinned. No fertiliser was applied and irrigation used only once at Soe to support establishment under unusually dry conditions at that time. Weeds were removed by hand. Establishment was successful at all sites except for Ulupulu and Sillu, which were excluded from subsequent analyses.

Plots were either grown continuously over a full growing season (December/January to July/August) at Naibonat and Soe (2010/11) or in a series of (typically 2 or 3) growth cycles (‘re-growth’ plots) initiated by sowing and thereafter cutting to 5–10 cm height and removing the cut material (all other sites) (Table 1). There was no attempt to control damage by diseases or insects which may have otherwise affected herbage production.

Plant performance measurements

Plant populations were measured by counting individual plants in central rows of plots 2 to 4 weeks after sowing to confirm satisfactory establishment. There were no further assessments of plant populations, but percentage cover was estimated at some sites immediately prior to biomass sampling. Above-ground biomass was measured approximately 8, 16 and 24 weeks after sowing in the continuously grown plots and immediately before cutting for the other experiments (specific timings for each site provided in Table 1). One or 2 randomly placed quadrats (either 0.5 or 1.0 m^2) were used to define sampling areas in each plot. Permanently marked areas were used for ‘re-growth’ areas, whereas different locations in the plots were sampled for the continuously grown experiments, avoiding previously sampled areas. Plants were cut at 5–10 cm using a sharp bush knife and the fresh material weighed. Sub-samples were collected where biomass samples were large (>400 g/quadrat) and also weighed fresh (immediately after cutting). The whole or sub-sample fresh material was transported to a weather-proof central location and either air- or oven-dried (70 °C) until constant weight to determine dry matter content and calculation of herbage yield dry matter (DM) per unit area.

The incidence of flowering was monitored at selected sites in the 2006–07 series of assessments and at all sites after 2010 through regular visits. The date of the first fully expanded inflorescence in each plot was recorded and numbers of fully expanded inflorescences counted within marked areas (0.5 or 1.0 m^2 quadrat) areas every 1–2 weeks (detailed results not presented in this paper). Observations relating to the incidence of pests and diseases and other factors which could affect plant growth (e.g. soil moisture deficit) were recorded to aid the interpretation of results.

Statistical analysis

The field data were converted to standardised units to check for inconsistencies attributable to errors of sampling measurements. All statistical analyses were conducted using Genstat™ software (VSN International 2014). Each site was analysed as a separate experiment. Simple one-way analysis of variance was used to compare means. Those with a significant F value were compared with Fischer’s least significant difference (P=0.05) procedure.

Table 3. Mean seedling density (plants/m^2 2–4 weeks after sowing) of herbaceous legumes sown using broad-cast (B), 'dibble' (spaced) and row planting in small-plots in eastern Indonesia.

Species	Identifier[1]	West Timor									Flores				Sumba		
		Naibonat	Biloto	Kletek	Kakaniuk	Sillu	Usapinonot	Soe	Naibonat	Naibonat	Marapokot	Nakuramba	Ulupulu	Wolomasi	Ranokolo	Milpinga	Wangga
		2006	2007	2007	2007	2007	2007	2010	2010	2011	2011	2011	2011	2011	2017	2016	2016
		B	'Dibble' pole													Row	
Aeschynomene americana	Glenn	S[2]															
Alysicarpus vaginalis	NS	P															
Arachis pintoi	Amarillo					2											
Centrosema molle	Cardillo							20	24	40	27	57	57	76	8	42	38
Centrosema pascuorum	Cavalcade	S	15	19	14	10	19	6	24	52				52	21		
C. pascuorum	Bundey							18	20	51							
Clitoria ternatea	APG52830							7	9						21	25	19
C. ternatea	Milgarra	S	12	19	12	11	7	14	26	73		55		32		7	5
Desmanthus leptophyllus	APG84431																
D. pernambucanus	NS	S	10	51	21	12	68										
D. virgatus	NS															12	11
D. virgatus	Marc		13	77	24	21	21									1	
D. virgatus	APG84369														6.5	57	
D. virgatus	APG48643															39	
D. virgatus + bicornutus + leptophyllus	Progardes															9	6
Lablab purpureus	Highworth		5	7		5	5	14	10								
L. purpureus	APG13483								5	11							
L. purpureus	Endurance							13	9								
L. purpureus	Rongai							20	12								
Macroptilium bracteatum	Cadarga	S	16	72	20	11	8	20	47								
M. bracteatum	Juanita							23	44	13	91	35	61				25
Macroptilium gracile	Maldonado					8			24								

Continue

Species	Identifier[1]	West Timor									Flores				Sumba		
		Naibonat	Biloto	Kletek	Kakaniuk	Sillu	Usapinonot	Soe	Naibonat	Naibonat	Marapokot	Nakuramba	Ulupulu	Wolomasi	Ranokolo	Milpinga	Wangga
		2006	2007	2007	2007	2007	2007	2010	2010	2011	2011	2011	2011	2011	2017	2016	2016
		B	'Dibble' pole													Row	
Mucuna pruriens	APG51786									2							
Stylosanthes hamata	Verano		P			39	53										
Stylosanthes guianensis	NS*			32	102	17	26	25									
S. guianensis	ATF3308									38							
S. guianensis	ATF3309									41							
Stylosanthes seabrana	NS		15	40	7	16	12										
S. seabrana	Primar														6	54	
S. seabrana	Unica															54	24
Vigna luteola	Dalrymple							13	18.0	71					21	25	32
Vigna unguiculata	Arafura							13	12.5								
P-value								0.013	<0.001	0.002	0.017	0.451	0.205	0.024	<0.001	<0.001	<0.001
LSD (P=0.05)								7	10	21	36	49	148	26	4	19	7

[1] Taxon=a cultivar unless prefixed where APG refers to current Australia Pasture Genebank records. NS=taxon not specified (not specifically known). NS*=Brazilian type.

[2] Plant populations were not measured at Naibonat in 2006, but success of establishment recorded by visual assessment: successful (S) or poor (P)

Results

Plant establishment

Plant establishment was highly successful at most sites with either 'dibble' or row (furrow) sowing techniques with mean values of between 20 and 90 plants/m^2 for most legumes and few with less than 5 (Table 3). Of the 'dibble' planted sites, plant populations were highest overall at Naibonat (lowland, West Timor), despite low levels of rainfall recorded after sowing, and the small sites on Flores where rainfall was higher after sowing (Table 3). Row planting resulted in suitable populations for forage production (15–50 plants/m^2) at the 2 Sumba sites with no obvious differences in establishment performance between legumes originating from the same seed lot and sown at both sites. Broadcast planting at Naibonat (2006) resulted in poor establishment of some legumes (*A. vaginalis* and *S. hamata*) but those with larger seeds established well (*C. pascuorum* and *C. ternatea*).

There were differences in plant population density between legume species. Legumes with seeds of moderate size and moderate sowing rates (*Centrosema*, *Clitoria* and *Macroptilium*) mostly had higher plant populations when both sowing methods were used. However, the largest seeded legumes (*Lablab*, *Mucuna*), which were sown at lower sowing numbers, tended towards low populations. Plant populations of the small, typically hardseeded legumes (*Desmanthus* and *Stylosanthes*) were highly variable, and performance was generally better using row planting, although comparisons were over differing years between the 'dibble' (2017), row-planted (2016) and broadcast-sown (2006) sites so the results are not definitive.

Biomass production without cutting (cumulative yields)

In the first experiment sown in late March 2006, 7 legume genera (*Aeschynomene*, *Alysicarpus*, *Centrosema*, *Clitoria*, *Desmanthus*, *Macroptilium* and *Stylosanthes*) were assessed on a Vertisol in a lowland environment on West Timor (Naibonat) (Table 4). *A. vaginalis* established poorly and seedlings grew slowly (yellowed plants). All legumes established and grew vigorously, except *S. hamata* 'Verano' (seedlings remained yellow and stunted). Early to mid-season biomass was greatest in *C. pascuorum* and *C. ternatea* with yields greater than 3 t DM/ha by 111 days after sowing. Subsequent yields declined slightly under drying soil conditions as growth slowed and leaves were shed, whereas *D. pernambucanus* continued to grow to yield 5.7 t DM/ha by the end of the experiment: much of this late season growth was stem. Verano stylo recovered to yield nearly 3 t DM/ha by 111 days with little measurable growth thereafter, whereas *A. americana* and *M. bracteatum* produced low yields.

The cumulative biomass yields of a similar suite of legumes were also measured on West Timor on Inceptisol soils in 2007. The 4 sites represent upland (Biloto and Usapininot) and lowland (Kletek and Kakaniuk) environments, the latter having a high winter rainfall component (Table 2). All were sown in February or March and assessed over ~200 days. All established well using the 'dibble pole' method, but plant populations 28 days after sowing varied considerably between lines. Small-seeded legumes (*Desmanthus*, *Macroptilium* and *Stylosanthes*) were particularly variable, ranging from ~10 to ~70 plants/m^2 (Table 3).

High cumulative biomass yields were measured at all sites (Table 4). The shrub legume *S. seabrana* accumulated very high biomass yields (5.9–9.8 t DM/ha) over the entire growing season. The *Desmanthus* spp. exhibited a similar growth pattern, with *D. pernambucanus* tending to out yield *D. virgatus*. The herbaceous legumes had lower yields. Cavalcade (*C. pascuorum*) and Milgarra (*C. ternatea*) performed similarly to results in the Vertisol site assessed the previous year, producing maximum herbage yields of 2–4 t DM/ha of leaf and (non-woody) stem. Highworth (*L. purpureus*), an annual or short-lived herbaceous legume, produced moderate levels of early-season biomass at 140–150 days after sowing but growth slowed towards the end of the season and herbage yield declined in one instance as leaves were shed. Cadarga (*M. bracteatum*), a short-lived perennial legume, grew well on most sites and accumulated biomass over the entire season to produce 2.2–4.9 t DM/ha.

Seventeen legumes were grown during 2010 without cutting at Naibonat (similar Vertisol soil as for the 2006/07 study) and 13 at an upland Alfisol site (Soe) (Table 5). Two *S. guianensis* lines established successfully at Naibonat but failed to grow beyond seedlings and were omitted from the experiment.

Table 4. Mean above-ground biomass (oven-dried material t/ha) of herbaceous legumes grown continuously (no cutting) at the first round of plant evaluation on West Timor[1].

Species	Identifier	Naibonat				Biloto				Kletek				Usapinonot			
		Vertisol / 50[2]				Inceptisol / 560				Inceptisol / 70				Inceptisol / 360			
		2006 (sown 23 Mar.)[3]				2007 (18 Feb.)				2007 (28 Mar.)				2007 (14 Feb.)			
		28[4]	56	111	159	94	150	197	90	155	205	90	140	209	84	153	197
A. americana	Glenn	0.10	0.40	1.15	0.95												
C. pascuorum	Cavalcade	0.20	2.50	3.60	3.20	3.51	2.88		0.86	1.62		2.44	3.27		2.70	2.93	4.40
C. ternatea	Milgarra	0.05	1.45	3.25		3.25	3.05	3.80	0.81	1.93	3.48	2.38	2.86	4.17	1.31	2.06	2.31
D. pernambucanus	NS	0.10	0.52	4.45	5.75	0.00	0.47		0.43	1.09	2.41	0.83	1.79	7.10	0.89	2.61	4.16
D. virgatus	Marc					0.88	0.08		0.28	0.05	1.98	1.50	1.17	2.17	0.51	0.40	1.60
L. purpureus	Highworth					4.25	1.76		0.98	1.42		1.86	2.95		1.12	1.40	1.19
M. bracteatum	Cadarga	0.02	0.95	1.00		1.50	1.76	4.95	1.81	2.23	3.05	0.65	0.96	4.85	0.26	1.36	2.22
S. guianensis	NS*					1.36	2.32	6.48	0.05	1.28	3.09	0.05	0.39	3.92	0.75	2.14	4.61
S. hamata	Verano				3.05												
S. seabrana	NS					1.93	4.02	9.80	0.26	4.08	5.05	0.54	2.65	7.87	0.23	3.50	5.90

[1] Herbage yields not presented for Sillu due to poor growth after establishment.
[2] Soil type / elevation (masl)
[3] Year of biomass assessment
[4] Weeks after sowing or cutting
Source: Dalgliesh et al. 2014 (project final report) and Budisantoso et al. 2006 (Indonesian national seminar series).

Table 5. Mean above-ground biomass (air-dried material t/ha) of herbaceous legumes grown continuously (no cutting) at lowland Vertisol (Naibonat) and upland Alfisol (Soe) sites on West Timor.

Species	Identifier	Naibonat (1)						Naibonat (2)		Soe	
		2010 (sown 11 Mar.)[1]			2011 (cut back 11 Jan.)			2011 (sown 22 Feb.)		2010 (sown 27 Mar.)	
		61[2]	124	217	52	113	173	71	132	63	124
C. molle	Cardillo	0.74	2.07	5.83	0.91	1.13	0.83	0.09	0.45	0.02	0.34
C. pascuorum	Bundey	2.29	7.24	6.61	0.75	2.77	1.50	2.25	2.20	0.03	0.23
C. pascuorum	Cavalcade	3.04	7.95	4.32	1.62	4.30	1.60	3.30	1.85	0.02	0.28
C. ternatea	APG52830	2.10	3.23	5.48	1.91	2.07	1.27	-	-	0.05	0.20
C. ternatea	Milgarra	2.41	3.85	5.20	1.98	2.27	1.17	1.85	1.40	0.02	0.17
L. purpureus	APG13483	4.46	4.62	6.75	-	-	-	1.60	0.30	-	-
L. purpureus	Endurance	2.62	2.91	3.92	-	-	-	-	-	0.07	0.16
L. purpureus	Highworth	3.24	4.90	3.84	-	-	-	-	-	0.64	0.39
L. purpureus	Rongai	3.58	3.86	5.90	-	-	-	-	-	0.45	0.37
M. bracteatum	Cadarga	4.00	5.34	4.91	-	-	-	-	-	0.04	0.12
M. bracteatum	Juanita	3.28	5.45	5.89	-	-	-	0.14	0.60	0.03	0.21
M. gracile	Maldonado	0.99	1.96	2.32	-	-	-	-	-	-	-
M. pruriens	APG51786	3.54	7.52	3.31	-	-	-	-	-	0.02	0.17
V. luteola	Dalrymple	1.83	3.37	4.97	-	-	-	-	-	0.21	0.11
V. unguiculata	Arafura	2.09	2.98	2.30	-	-	-	1.70	0.55	-	-
P-value		<0.001	<0.001	0.007	<0.001	0.094	0.632	0.005	0.033	0.001	0.045
LSD (P=0.05)		0.94	1.56	2.37	0.48	2.23	1.20	1.20	1.15	0.24	0.17

[1] Year of biomass assessment
[2] Days after sowing or cutting

High yields of air-dried biomass were measured 16 and 24 weeks after sowing at the lowland site where mean monthly daily temperatures ranged from 25.8 to 27.7 °C. The highest yielding taxa were *Centrosema*, *Clitoria*, *Lablab*, *Mucuna*, *Macroptilium* and *Vigna* which all produced 5–8 t DM/ha over the growing season. Some produced maximum biomass values 16 weeks after sowing (*C. pascuorum*, some *L. purpureus*, *M. bracteatum* and *Mucuna pruriens*) with little subsequent increase in herbage yield (or decline in yield as they dry). Others continued to accumulate biomass until the final measurement 24 weeks after sowing (*C. molle*, *C. tenatea* and *Vigna luteola*). *C. molle*, *C. pascuorum* and *C. clitoria* survived the dry season and were cut to ~10 cm during January 2011. Second year herbage yields were variable, potentially due to extremely wet conditions during February, March and April (Table 3). Sixteen-week herbage yields ranged from 1 t/ha (*C. molle*) to 4 t/ha (*C. pascuorum* Cavalcade). The same species, plus the better performing *L. purpureus* (APG13483), were re-sown at Naibonat in late February 2011 and growth monitored for 24 weeks. Cavalcade (*C. pascuorum*) again produced the highest biomass yields, with 3.3 t DM/ha produced 10 weeks after sowing, with the others having low (*C. molle* Cardillo) to moderate yields.

Herbage yields on the Alfisol upland site (Soe) after sowing in late March were poor. Highworth (0.64 t DM/ha) and Rongai (0.45 t DM/ha) (*L. purpureus*) had the highest yields 9 weeks after sowing. Cool (mean daily temperatures of ~20 °C) and wet conditions between May and August were associated with poor plant growth in all legumes, with most dying out over this period. The exception was Cardillo (*C. molle*) which persisted until November, although herbage yields were low when measured in July.

Biomass production with cutting

Herbage production of a range of legumes was measured after sowing and plant regrowth after a series of cutting cycles on Vertisol and Alfisol soils in Sumba and Flores (Table 6). Milgarra (*C. ternatea*) had the highest overall herbage yields (4.7 and 7.1 t air-dried material/ha) on the 2 Vertisol sites, due to a combination of rapid growth after establishment and regrowth after cutting.

Table 6. Mean[1] above-ground biomass (air-dried material t/ha) of herbaceous legumes grown in cutting cycles at lowland (Wangga) and upland (Milipinga) sites on Sumba and Flores.

Species	Identifier	Sumba						Flores		
		Milipinga (sown 23 Jan.) Alfisol, 240 masl			Wangga (sown 22 Jan.) Vertisol, 85 masl			Ranokolo (sown 21 Feb.) Vertisol, 300 masl		
		96 DAS	98 DAC	Flower	96 DAS	98 DAC	Flower	84 DAS	84 DAS	Flower
C. pascuorum	Bundey							2.18	0.32	Weak
C. pascuorum	Cavalcade	0.30^{de}		Strong	2.66	0.59	Strong	1.04	0	Strong
C. ternatea	Milgarra	0.19^{cd}		Strong	3.31	3.79	Strong	2.31	2.35	Strong
D. leptophyllus	APG84431	0.09^{bc}		Weak	1.28	1.19	Strong			
D. virgatus	Marc	0.04^{b}		Weak	1.30	0.71	Strong			
D. virgatus	APG84369	0.01^{a}		Weak						
D. virgatus	APG48643	0.41^{de}		Strong				0.21	1.73	Strong
D. virgatus	Progardes	0.39^{de}		Weak						
L. purpureus	Highworth	0.09^{bc}		Weak	1.48	0	None			
M. bracteatum	Juanita				2.86	0.71	Strong			
S. seabrana	Primar	0.69^{e}		Strong				0.14	0.49	Strong
S. seabrana	Unica	0.75^{e}		Strong	2.31	2.25	Strong			
V. luteola	Dalrymple	0.22^{cd}		Weak	1.92	0.63	Weak	3.24	1.17	None
P-value		<0.001			0.050	<0.001		<0.001	<0.001	
LSD (P=0.05)					1.43	568		0.41	0.64	

[1] Back transformed means (log$_{10}$ transformation) are presented for Milipinga. Backtransformed means with the same letter are not considered to be different at the 95% confidence level. DAS=Days after sowing; DAC=Days after cutting Strong=flowers in all plots before biomass sampling; Weak=flowers in few plots before biomass sampling; None=flowers not detected

The sub-shrub legumes *S. seabrana* and *D. leptophyllus* also regrew well after cutting, but overall biomass yields were lower than for Milgarra. Bundey and Cavalcade (*C. pascuorum*), Juanita (*M. bracteatum*) and Dalrymple (*V. luteola*) initially yielded well, but regrew poorly after cutting, while Highworth (*L. purpureus*) did not regrow at all (one site).

Herbage yields were low 14 weeks after sowing at the upland Alfisol site on Sumba despite receiving over 300 mm rainfall. Regrowth after cutting was also poor with insufficient biomass to complete meaningful assessments. This regrowth period coincided with low monthly rainfall and notably dry soil conditions. The best performing legumes under this growing environment were the sub-shrub legumes (*Stylosanthes* and *Desmanthus*), which were the only legumes to persist through the dry season (observation only).

Peak season biomass in different environments

Total seasonal herbage production after a January-March sowing, either grown continuously or with 8- to 14-week cycles of defoliation, are presented for all sites in Table 7. The length of the measured growing season for continuously grown plants varied from 63 days at Soe, where poor growth curtailed biomass measurements, to 217 days at Naibonat.

The highest (7–8 t DM/ha) herbage yields were achieved by Bundey and Cavalcade (*C. pascuorum*) assessed at many sites and *M. pruriens* at Naibonat and Milgarra (*C. ternatea*) at Wangga. These were both lowland Vertisol sites where biomass was accumulated over an extended period. Legumes which achieved 4–6 t DM/ha included *C. molle*, *C. ternatea*, *L. purpureus*, *M. bracteatum* and *V. luteola*, also on Vertisol soils either on West Timor (Naibonat) or Flores (Ranokolo). Biomass yields tended to be lower at the sites subjected to cutting cycles, although not in all instances. For example, the highest *C. ternatea* yield was achieved under cutting. Unica (*S. seabrana*) also yielded well, producing a total of 4.5 t air-dried biomass /ha on a Vertisol under cutting (one site only).

The legumes which ranked highly across a range of sites were *C. pascuorum* and *C. ternatea*. Cavalcade (*C. pascuorum*) ranked highest when grown continuously on Vertisols, while *C. ternatea* tended to rank best under cutting. Other legumes ranked highly across a limited number of sites or cutting regimes. *C. ternatea* consistently ranked highly when grown on Vertisols on Sumba and Flores, while *C. pascuorum* grew well on both Vertisols and Alfisols. The cyclical harvesting and removal of biomass appeared to also influence total biomass of some other legumes which ranked highly for total seasonal yield. *L. purpureus* and *M. pruriens*, both short-lived (annual or biennial) twining legumes, produced high amounts of biomass when grown without cutting on West Timor but had low overall biomass when grown in cutting cycles on Sumba. *C. molle*, another twining legume but with a longer life cycle, ranked highly for total seasonal biomass under both continuous growth and cutting regimes.

The site at Milipinga on Sumba represented a quite different growing environment (upland Alfisol and low rainfall) to the other sites. The highest ranked legumes were the 2 *S. seabrana* cultivars and 2 of the 5 *Desmanthus* sp. cultivars or lines (these had the highest plant populations). Cavalcade (*C. pascuorum*) also grew well initially.

Insects and disease

C. ternatea was occasionally damaged by the leaf-chewing larvae of a butterfly (*Catopsilia* sp.) commonly observed during the wet and early-dry seasons. Damage (60–80% of leaves) was first recorded at Naibonat in 2006 and endosulfan was applied to control the caterpillar larvae. Endosulfan was not used in any of the other experiments and it was not considered a useful option for smallholder farmers. Moderate damage was recorded at Naibonat during 2010 to both lines assessed, and this may have reduced biomass over the season. Lesser damage was noted on leaves of *L. purpureus* and *V. luteola* at the same site, but this was caused by other insects. Leaf damage was also noted on *C. pascuorum* grown at Nakuramba but the cause was unknown. Pod borers (suspected to be *Helicoverpa* sp.) were also observed on *L. purpureus* but are not expected to have affected biomass yields. There was no obvious disease damage at any of the sites although extremely poor growth of *S. guianensis* at Naibonat in 2010 could possibly be attributed to soil-borne pathogens following wet conditions.

Table 7. Peak above-ground biomass (oven or air dried material t/ha) of herbaceous legumes grown in eastern Indonesia either continuously or in cycles of cutting and regrowth.

Species	Identifier	Continuously grown[1]									Cutting and regrowth cycles[2]						
		West Timor									Flores					Sumba	
		Naibonat Vertisol, 50 masl	Biloto Inceptisol, 560 masl	Kletek Inceptisol, 70 masl	Kakaniuk Inceptisol, 50 masl	Usapinonot Inceptisol, 360 masl	Soe Alfisol, 900 masl	Naibonat Vertisol, 50 masl	Naibonat Vertisol, 50 masl	Naibonat Vertisol, 50 masl	Marapokot Vertisol, 15 masl	Nakuramba Vertisol, 50 masl	Ulupulu Insceptisol 530 masl	Wolomasi Vertisol, 715 masl	Ranokolo Vertisol, 300 masl	Milipinga Alfisol, 240 masl	Wangga Vertisol, 85 masl
		2006	2007	2007	2007	2007	2010	2010 (year 1)	2010 (year 2)	2011	2011	2011	2011	2011	2017	2016	2016
		111 159[3]	*150* 197	205	*140* 209	*153* 197	*63* 124	*124* 217	113	*71* 132	112	168	112	168	168	96	194
		1[4](o)	1(o)	1(o)	1(o)	1(o)	1(o)	1(a)	1(a)	1(a)	2(a)	3(a)	2(a)	3(a)	2(a)	1(a)	2(a)
A. americana	Glenn	1.15															
C. molle	Cardillo						0.34	5.83	1.13	0.45	0.91*	1.72	0.68*	1.39			
C. pascuorum	Bundey						0.23	7.24	2.77	2.25					2.50		
C. pascuorum	Cavalcade	3.60	2.88	1.62	3.27	4.40	0.28	7.95*	4.30	3.30*				2.07	1.04	0.36	3.25
C. ternatea	APG52830						0.20	5.48	2.07								
C. ternatea	Milgarra	3.25	3.80	3.48	4.17	2.31	0.17	5.20	2.27	1.85		2.84*		2.45*	4.67*	0.19	7.11*
D. leptophyllus	APG84431															0.09	2.47
D. pernambucanus	NS	5.75*	0.47	2.41	7.10	4.16											
D. virgatus	Marc		0.08	1.98	2.17	1.60										0.04	2.02
D. virgatus	APG84369															0.01	
D. virgatus	APG48643														1.94	0.41	
D. virgatus	Progardes															0.40	
L. purpureus	APG13483							6.75		1.60							
L. purpureus	Endurance						0.16	3.92									
L. purpureus	Highworth		1.76	1.42	2.95	1.40	0.64*	4.90								0.10	1.48

Continue

Species	Identifier	Continuously grown[1]									Cutting and regrowth cycles[2]						
		West Timor									Flores					Sumba	
		Naibonat Vertisol, 50 masl	Biloto Inceptisol, 560 masl	Kletek Inceptisol, 70 masl	Kakaniuk Inceptisol, 50 masl	Usapinonot Inceptisol, 360 masl	Soe Alfisol, 900 masl	Naibonat Vertisol, 50 masl	Naibonat Vertisol, 50 masl	Naibonat Vertisol, 50 masl	Marapokot Vertisol, 15 masl	Nakuramba Vertisol, 50 masl	Ulupulu Insceptisol 530 masl	Wolomasi Vertisol, 715 masl	Ranokolo Vertisol, 300 masl	Milipinga Alfisol, 240 masl	Wangga Vertisol, 85 masl
		2006	2007	2007	2007	2007	2010	2010 (year 1)	2010 (year 2)	2011	2011	2011	2011	2011	2017	2016	2016
		111 159[3]	*150* 197	205	*140* 209	*153* 197	*63* 124	*124* 217	113	*71* 132	112	168	112	168	168	96	194
		1[4](o)	1(o)	1(o)	1(o)	1(o)	1(o)	1(a)	1(a)	1(a)	2(a)	3(a)	2(a)	3(a)	2(a)	1(a)	2(a)
L. purpureus	Rongai						0.45	5.90									
M. bracteatum	Cadarga		1.76	3.05	4.85	2.22	0.12	5.34									
M. bracteatum	Juanita						0.30	5.89			0.32	2.00	0.35				3.58
M. gracile	Maldonado							2.32									
M. pruriens	APG51786							7.52									
S. guianensis	NS		6.48	3.09	3.92	4.61											
S. hamata	Verano	3.05															
S. seabrana	NS		9.80*	5.05*	7.87*	5.90*											
S. seabrana	Primar														0.63	0.69	
S. seabrana	Unica															0.76*	4.56
V. luteola	Dalrymple						0.17	4.97		1.70					4.40	0.22	2.56
V. unguiculata	Arafura						0.21	2.98									

Shaded panels represent legumes with mean total biomass >20% of the site mean; Panels with an * represent the highest value for that site; Drying method (o=oven; a=air)

[1] Where continuously grown, the maximum value of sampled biomass is presented (normal font=end of season; italics=mid-season)

[2] Where grown in cycles of cutting and regrowth, total values of biomass measured at the end of each growth cycle are presented

[3] Growth period (days)

[4] Number of growth cycles

Table 8. Summary of better-performing legumes under a range of growing environments and management in eastern Indonesia.

Legume species	Australian cultivars (lines) tested	Growing environment(s)[1]	Successful establishment method(s)	Regrowth after cutting	Typical herbage yields under cutting[2]	Typical herbage yields without cutting[2]	Recommended system	Other considerations
Herbaceous legumes								
C. pascuorum	Cavalcade Bundey	Vertisols, Inceptisols; upland and lowland	Dibble pole, row, broadcast	Inconsistent, poor when mature or under dry conditions	1–3	2–8	Single crop; fresh cut or hay	Easy to harvest fresh or for hay
C. molle	Cardillo	Vertisols, Inceptisols; best on an Alfisol (low yields overall); upland and lowland	Dibble pole	Moderate	0.5–1.5	0.5–5.5	Regrowth fodder crop (fresh or hay) or graze directly	Low growing and difficult to cut
C. ternatea	Milgarra APG52830	Vertisols, Inceptisols; upland and lowland	Dibble pole, row, broadcast	Excellent under a range of conditions	2–7	2–5	Cutting cycles or as a single crop; fresh cut or hay	Easy to harvest. Defoliation by Catopsilia butterfly larvae.
L. purpureus	Highworth Rongai	Vertisols, Inceptisols; high rank on Alfisol (low yields overall); upland and lowland	Dibble pole	Poor	0–1.5	2–6	Grow as a single crop forage crop; fresh cut	Leaves shatter when dry
M. bracteatum	Cadarga Juanita	Vertisols, Inceptisols; lowland	Dibble pole, row, broadcast	Inconsistent, regrew well on a Vertisol	0.5–3.5	2–5	Single crop, regrowth on Vertisols; fresh cut	Leaves shatter when dry
M. pruriens	(APG51786)	Vertisol; lowland	Dibble pole	Not tested	–	7.5	Single crop forage crop; fresh cut or hay	Leaves fell when mature
V. luteola	Dalrymple	Vertisol; lowland	Dibble pole, row	Moderate under good growing conditions	2.5–4.5	2–5	Single crop forage crop; fresh cut or hay	Susceptible to insects
Shrub legumes								
D. leptophyllus	(APG84431)	Vertisol; lowland	Row	Slow regrowth	0–2.5	2.5	Semi-permanent fodder banks/pasture	Leaf drop when dry, stemmy when mature
D. pernambucanus	'Common'	Vertisol, Inceptisol; lowland and upland	Broadcast	Not tested	–	2–7	Semi-permanent fodder banks/pasture	Leaf drop when dry, stemmy when mature
D. virgatus	Marc Progardes (APG84369) (APG48643)	Vertisol; lowland	Row, dibble pole	Slow regrowth	0–2	0–2	Semi-permanent fodder banks/pasture	Leaf drop when dry
S. guianensis	(Brazilian)	Inceptisol; lowland and upland	Dibble pole	Not tested	–	3–6.5	Single crop; fresh cut or hay	Stemmy when mature
S. hamata	Verano	Vertisol (limited evaluation)	Dibble pole	Not tested	–	3	Semi-permanent fodder banks/pasture	Low growing
S. seabrana	Primar Unica (common)	Inceptisol, Vertisol, best on Alfisols overall; lowland and upland	Row	Moderate regrowth	4.5–6.5	5–9	Semi-permanent fodder banks/pasture	Stemmy when mature

[1] Herbage yields were low, overall, on Alfisols

[2] (t DM/ha)

Discussion

Application and scope of the research program

The overarching aim of the plant evaluation was to identify legumes which could be grown for animal (principally cattle, but also for goats) production within mixed cropping systems. A suite of mostly herbaceous legumes were assessed (as opposed to tree) legumes because these could conceivably be grown in rotation with other food crops or as an inter-crop, for example as a 'relay' where the legumes are sown into the developing food crop (maize) and the fodder grown and utilised after the food crop is harvested. Such systems were not obvious at the onset of the study, but were identified over the course of experimentation and farmer extension resulting in productive grain (maize, rice) crop-fodder systems in which the use of forages did not reduce or even increased grain crop yields (through increased nitrogen supply) (Bell et al. 2022).

Legume selection was biased to those previously developed and adopted in northern Australia. The recently updated Tropical Forages selection tool (Cook et al. 2020) also provided a useful reference for identifying suitable species and cultivars/lines for assessment. The legumes were assessed mostly over one growing season with establishment and assessment in the same year. Establishment was during the higher rainfall summer months when conditions were conducive to establishment and growth under rainfall, similar to other annual cash or staple food crops (mung beans, maize). There is an opportunity, however, to also grow crops during the dry season after rice production (paddy systems) (Bell et al. 2022). These systems seem particularly well-suited to herbaceous legumes with larger seeds such as *C. pascuorum* and *C. ternatea*.

Relevance and interpretation of data for identifying suitable legumes

Dried herbage biomass over 1 or (in one case) 2 growing seasons (as opposed to persistence and herbage yield over time), was used as the principal measure to rank legumes across environments. Biomass production under continuous growth was initially used to rate the adaptation of legumes to various soils and climates. Subsequent experiments using the more promising legumes measured regrowth following cutting and removal of the herbage as would conceivably be used for feeding livestock, either fresh or conserved as hay. Oven dried biomass was determined for the initial experiments when there was good access to ovens and air-dried biomass (i.e. hay) thereafter at more remote sites. In a similar growing environment (Northern Territory of northern Australia) Cavalcade (*C. pascuorum*) hay (March harvest) was found to have a moisture content of 13% (i.e. 87% oven DM) after sun drying, declining to 8% in dry-season storage (Regan 1997). This is safely below the 18% recommended for safe storage in eastern Indonesia (Nulik et al. 2013). It is reasonable to expect, therefore that the legumes grown and air-dried in NTT had dry matter contents in the order of 10–15% lower than oven results. These were not considered to have influenced rankings of the legumes.

Secondary criteria for selection included ease of cutting and baling and seed collection. Larger seeds and lower levels of pod shattering are considered advantageous in smallholder systems where self-harvest of seeds can improve the sustainability of forage systems requiring regular sowing. Plant nutrient content was not assessed in these experiments. However, as most of the taxa tested have previously been well-researched, values of digestible energy and protein at different growth stages can readily be sourced in most instances (Cook et al. 2020). All of the legumes assessed are considered palatable to livestock, but vary in feed value based on plant structure and growth stage.

Legumes as short-term fodder crops in eastern Indonesia

The best overall legumes for growing between annual grain crops were *C. pascuorum* and *C. ternatea*. Both are twining herbaceous legumes with high feed value. Whereas *C. ternatea* has an erect, climbing habit, *C. pascuorum* has decumbent, sprawling growth (Cook et al. 2020). Other legumes which ranked highly in some environments included *C. molle*, *L. purpureus*, *M. bracteatum*, *M. pruriens* and *V. luteloa*.

C. pascuorum cultivars (Cavalcade and Bundey) produced high annual yields (up to 8 t air dried herbage/ha). Herbage yields compared favourably with a range of *C. pascuorum* accessions grown in a similar climatic zone in northern Australia (Katherine, Northern Territory) where fertiliser phosphorous and sulphur were applied prior to sowing by broadcasting (Clements et al. 1984). Both varieties are grown commercially for hay production in the Northern Territory where they are mostly incorporated into pellets for feeding cattle during live export (Cameron 2005), potentially providing an option for NTT to support live export between islands. In the

NTT experiments Cavalcade tended to out yield Bundey when compared at the same site, indicating Cavalcade may be best suited to eastern Indonesia; however, there may a role for Bundey in wetter environments. Although *C. pascuorum* grew vigorously at most sites, regrowth after cutting and removing herbage was inconsistent and relatively poor after cutting under dry conditions. These results indicate *C. pascuorum* is best grown as a single forage crop and regrowing after cutting should only be attempted under favourable growing conditions (high soil moisture or access to irrigation).

C. ternatea produced up to 5 t air dried material/ha over the growing season when grown continuously on Vertisols and up to 7 t air dried material/ha under cutting cycles. Production also ranked highly compared to other legumes on Inceptisol and Alfisol soils, the broad adaptation being consistent with previous adaptation studies in northern Australia (Hall 1985). The yields achieved in NTT were higher than recorded in replicated grazing-scale experiments on cropping soils in southern Queensland including Milgarra, where it took 3 years to achieve comparable yields on fertilised (P and S) Vertisols (Whitbread et al. 2005). The demonstrated capacity to regrow vigorously after cutting enables a series of forage crops to be harvested over a season as required and either fed fresh or conserved as hay. A perennial growth habit also means it can perform a useful role in longer-term grazing leys in cropping systems to provide high-quality feed and rejuvenate soils (Pengelly and Conway 2000). One potential management limitation, however, is occasional severe defoliation by larvae of butterflies (*Catopsilia* sp.) encountered over short periods during the key growing season. Given the capacity for *C. ternatea* to regrow after cutting, a strategy to avoid damage by larvae is to harvest fodder when large numbers of larvae are detected and allow the crop to regrow.

Other high-yielding legumes for short-term fodder production included *L. purpureus*, *M. bracteatum*, *M. pruriens* and *V. luteloa*, which all showed some potential as legumes which can easily be established and grow rapidly to provide useful amounts of biomass in eastern Indonesia. These legumes produced in the order of 5–7 t air dried material/ha under optimal conditions and were generally most productive on Vertisols. Herbage yields were comparable with those achieved under good growing conditions in Queensland (Pengelly and Conway 2000; Whitbread et al. 2005), but higher yields have been reported under optimum growing conditions (Cook et al. 2020). These legumes provide a useful forage option where high amounts of biomass are sought over short periods. All are recognised as annual or short-duration legumes of high forage value which can perennate under favourable conditions (Cook et al. 2020). Although yields were relatively low, Cardillo (*C. molle*) showed potential where other legumes had failed. Cardillo appears broadly adapted and robust, but the dense, low growth habit could interfere with hand harvesting.

A range of *Desmanthus* (3 species) and *Stylosanthes* (3 lines) were tested on Vertisol and Inceptisol soils on West Timor and later on an Alfisol and Vertisol soils on Sumba to identify robust, well adapted sub-shrub legumes which might have a role in permanent grazing (common grazing land). These perform well as permanent pastures in northern Australia (Clem and Hall 1994; Jones and Brandon 1998).

Desmanthus spp. proved particularly well-adapted to NTT. When initially tested on West Timor, *D. pernambucanus* grew slowly after establishment but continued to grow through the dry season to produce over 5 t DM/ha by the end of the season. There was a high proportion of stem, however, so feed value would have been relatively low. Establishment of *D. virgatus* was variable when later tested on Sumba and this appeared to influence biomass production. However, *Desmanthus* persisted on the Alfisol site whereas most other legumes died.

The performance of the *Stylosanthes* lines was more variable. *S. seabrana* was best adapted overall, similar to previous experience in northern Australia (Edye et al. 1998). A 'common' line produced exceptionally high yields (5.9 to 9.8 t DM/ha) over ~200 days on an Inceptisol on West Timor and later, Primar and Unica produced high-ranked yields on an Alfisol and Vertisol on Flores. These results indicate *S. seabrana* is broadly adapted to key soils in Eastern Indonesia. The other stylos grew poorly overall, except *S. guianensis* which yielded well (6.5 t DM/ha) on an Inceptisol.

Forage value

Forage value was not assessed during the studies, but nutrient values for the tested legumes are well documented in literature. The better performing legumes (*C. pascuorum* and *C. ternatea*) identified for short-term systems are known to have excellent feed value. Under small plot assessment conducted in north Queensland a range of *C. pascuorum* leaves had a mean nitrogen content of 2.4% (15% crude protein) and phosphorous and sulphur contents ranging from 0.15–0.18% and 0.19–0.23%, respectively (Clements et al. 1984; Clem and Hall 1994). Nitrogen contents of 2.8% and dry matter digestibilities of 66–74% were reported for irrigated *C. ternatea*, *C. pascuorum*, *L. purpureus* and *M. bracteatum* 90 days after planting on a Vertisol soil lowland site in West Timor (Hartutik et al. 2012). The other herbaceous legumes listed above also produce high quality fodder and none have any nutritional limitations, although low palatability has been reported for *M. pruriens* (Cook et al. 2020). Comparative studies found the feed value of the sub-shrub legumes *Desmanthus* spp. and *S. seabrana* tend to be lower than for *C. ternatea* (Jones et al. 2000) and the shrub legumes are considered of moderate feed value, however, and may have a useful role as fodder banks once established and managed appropriately.

Cattle production studies were completed in NTT within the broader research program using locally grown *C. ternatea* fed fresh or conserved as hay (Mayberry et al. 2021). It was found relatively small amounts of legume added to a typical local diet (native grasses and supplementation types) overcame weight loss in cows and heifers, decreased mortality in unweaned bulls and increased liveweight gain in bulls.

Forage systems and considerations for adoption in eastern Indonesia

Legumes with a range of growth habits and capacity to regrow after cutting were identified for Vertisols in eastern Indonesia, with fewer options for Alfisols and Inceptisols. The legumes which produced high amounts of biomass shortly after establishment but exhibited poorer regrowth after cutting (principally *C. pascuorum* but also *L. purpureus* and, potentially *M. pruriens*) have best potential for short-period intercrop systems, such as maize production with shorter growing seasons or ‘Rice-Rice-Legume’ or ‘Rice-Legume-Rice’ sequences using irrigation to supplement rainfall during the dry season. In complementary research conducted within the research program it was demonstrated *C. ternatea* could also be used in these systems because of its capacity to rapidly produce biomass after sowing (Bell et al. 2022). *V. luteola* and *M. bracteatum* could be used as an alternative to these species if longer growth periods are warranted.

C. ternatea provides the greatest flexibility for successive crop-forage systems because of rapid growth after establishment and the best capacity to regrow after cutting. Potential roles include forage crop production in rotation with rice in the lowland areas and with maize in the upland or drier areas with no additional irrigation. Multiple forage crops can be harvested and either fed fresh or conserved as hay and fed during times of fodder scarcity during the dry season in upland cropping systems when soil moisture limits fodder production or during the wet season in rice production areas where most available land is being used for grain production.

Another potential option to integrate legumes into crop production systems is to grow a ‘living mulch’ by sowing a vigorous grain such as maize into a live legume sward. Such methods can be used to suppress weeds and modify the soil environment to benefit crop production. In Nigeria, Akobundu and Okigbo (1984) demonstrated *C. pascuorum* effectively smothered weeds and maize could be successfully grown in the legume crop if the legume was suppressed before planting by cutting or defoliating with herbicide, although legume regrowth after cutting caused some reduction of yields. Such systems may benefit crop and cattle components in eastern Indonesia where they meet agronomic and cultural needs, but this requires further testing.

Conservation of fodder as legume hay to target feed gaps or for sale was demonstrated by the research team (Dalgliesh et al. 2014). *C. pascuorum* hay is routinely mechanically produced on a commercial scale in the Northern Territory of Australia (Cameron 2005) and *C. ternatea* is known to produce excellent hay (Cook et al. 2020). Both have been shown to produce excellent hay in eastern Indonesia with little loss of leaf when incorporated into small bales (Nulik et al. 2013). Hay can also be produced by most of the other legumes tested, but often with difficulty due to thick stems or the shedding of leaves when dry (Cook et al. 2020).

Two legume taxa (*Desmanthus* spp. and *S. seabrana*) were identified as having potential for longer term fodder banks or permanent pastures. They were well-adapted to the 3 soil types tested and *D. virgatus* and *S. seabrana* stood out as options on the Alfisol on Sumba, potentially providing options for extensive grass pastures used for common grazing systems. Higher yields of *D. pernambucanus*, an erect legume suited to fodder banks, than *D. virgatus*, a smaller type more commonly used in grass-pastures (Cook et al. 2020), in earlier studies indicates there might be merit in considering this species for grazing. Adoption would require further research into establishment systems under eastern Indonesian conditions due to the difficulty establishing these small-seeded legumes with high levels of hard seed dormancy (Burrows and Porter 1993; Peck et al. 2011).

Forage crop establishment and growth

The adoption by smallholder farmers of legumes within crop-forage systems (rotation, relay) is contingent on the ready supply of seeds for sowing and comparative ease of establishment. Legumes with larger seed and low levels of hard seed dormancy are generally easier to establish using smallholder methods (e.g. 'dibble' pole into rough tilth) as they will emerge from a range of sowing depths and do not require processing prior to sowing to overcome hard seed dormancy. *C. ternatea*, *C. pascuorum*, *L. purpueus* and *M. pruriens* all have relatively large seeds and low to moderate levels of hard seed dormancy compared to other legumes (*Desmanthus*, *Stylosanthes*) (Cook et al. 2020). In a series of small-lot experiments conducted within the research program, the 'dibble' pole and furrow sowing methods were found to provide higher plant populations and legume biomass of *C. ternatea* than broadcasting seeds (Nulik et al. 2017) supporting the results from the current study.

A component of the program investigated flowering for seed production of the more promising legumes identified in the program in a series of replicated experiments in northern Australia and 4 sites in eastern Indonesia (Nulik et al. 2016). Milgarra (*C. ternatea*) was found to be the most flexible seed crop due to indeterminate flowering, low levels of pod shattering (dehiscing) and the capacity to increase hand harvested yields by using trellises. Pods also present well for hand picking. Cavalcade and Bundey (*C. pascuorum*) had strong photoperiodic control over flowering which restricted the opportunity to harvest seeds during the year and pods were located within the crop canopy making harvest by hand-picking more difficult. These pods can also dehisce when dry, requiring more complex management to harvest seeds. Flowering of Highworth (*L. purpureus*) was under weaker photoperiodic control in eastern Indonesia than in northern Australia resulting in weak flowering, although good presentation and low levels of pod shattering mean hand harvest is relatively easy. Overall, seed production of *C. ternatea* is considered best suited for opportunistic harvesting by small holders as seeds can be readily hand-picked from forage crops over most of the year. The other species require special management for seed production to encourage vigorous flowering and recovery of seeds.

The legumes were grown without inoculating seeds with nitrogen fixing bacteria in most of the experiments. There were no obvious deficiencies for nitrogen (yellowing and poor growth) except possibly for *S. guianensis* grown at Naibonat in 2010. Specific bacterial strains are recommended in Australia for *M. bracteatum*, *Desmanthus* spp. and *S. seabrana*, but effective nodulation can often be achieved with native rhizobia for *C. ternatea*, *C. pascuorum* and *L. purpureus,* although application on a precautionary basis is often recommended when these, or closely related, species have not been grown previously (Cook et al. 2020). It is possible that inoculation with specific rhizobia could have increased yields, but the high forage yields often achieved indicate there was sufficient nitrogen in the soil or effective associations were formed with local bacterial strains. The use of rhizobia strains for use of the higher-performing legumes in Indonesia warrants further investigation, but is not considered a research priority.

Conclusions

A broad range of legumes have now been tested in eastern Indonesia for use in crop-livestock systems and a range of suitable legumes identified. They all establish readily from seed using local sowing practices and produced high levels of biomass without rhizobium seed inoculum.

C. pascuorum, *L. purpueus* and *M. pruriens* produced high amounts of biomass shortly after establishment during summer (January–March) but regrew poorly after cutting in most instances. These legumes are considered suitable for integrating into crop systems characterised by short intercrop periods, such as 'Rice-Rice-Legume' or 'Rice-Legume-Rice' sequences using irrigation to supplement rainfall during the dry season. *V. luteola* and *M. bracteatum* could be used as an alternative to these if longer growth periods are possible.

C. ternatea produced high biomass yields after summer sowing on Vertisol soils. Regrowth after cutting was vigorous across a range of environments and high fodder yields were accumulated over the growing season. These features present farmers with a range of options including forage production in rotation with rice in lowland areas or with maize in the upland or drier areas with no additional irrigation. Multiple forage crops can be harvested and either fed fresh or conserved as hay and fed during times of fodder scarcity.

Desmanthus species and *S. seabrana* show potential for use for longer-term fodder banks (*D. pernambucanus*) or pastures (*D. virgatus*, *S. seabrana*) on Alfisol, Inceptisol and Vertisol soils where forage production is produced outside of cropping areas.

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