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Herbaceous legumes provide several options for increasing beef cattle productivity in eastern Indonesia

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Abstract

Context. Increasing demand for livestock products in developing countries provides opportunities for smallholder farmers to increase and diversify their income through increased livestock production. However, livestock production in these systems is often limited by inadequate animal nutrition, and farmers need ways to increase the availability and quality of livestock feed without compromising yields of food crops or increasing the area of land planted to forages.

Aim. Using eastern Indonesia as a case study, we explore the potential for herbaceous legumes, integrated into existing mixed crop–livestock systems, to address specific production issues in smallholder beef systems.

Methods. Through a series of in-village feeding demonstrations, we tested three opportunities to increase livestock production through the use of herbaceous legumes: (*i*) increasing reproduction rates of cows by maintaining their liveweight (LW) and body condition score during the dry season; (*ii*) increasing the survival and LW gain of unweaned calves; and (*iii*) increasing LW gain of growing bulls.

Key results. Small amounts of legume (~10 g DM/kg LW) were enough to maintain LW of cows grazing poor-quality grasses and crop residues during the dry season. At higher levels of inclusion in the diet (~20 g DM/kg LW), feeding legumes increased the LW gain of growing cattle and survival of unweaned calves, providing benefits similar to a purchased concentrate, but at lower cost.

Conclusions. Our results demonstrate how strategic use of herbaceous legumes can increase beef production from low-input systems by maintaining LW of cows, and increasing survival of unweaned calves and LW gain of growing bulls.

Implications. Integration of herbaceous legumes into existing cropping systems removes many of the barriers to supplementary feeding. Improved livestock nutrition does not need to be based on purchased concentrates or increases in land used for forage production. The results are applicable to many other mixed crop–livestock systems throughout Southeast Asia.

Keywords: Bali cattle, *Clitoria*, crop–livestock systems, liveweight gain, Ongole cattle.

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Introduction

Increasing demand for livestock products throughout many parts of Asia presents important opportunities for smallholders to increase and diversify their farm income (Herrero *et al.* 2013). The move from subsistence to market-orientated farming is one of the three pathways out of poverty for the rural poor, as identified by the World Bank (2007). As in other parts of Southeast Asia, demand for beef is growing rapidly in Indonesia, driven by a growing population (BPS 2012), rapid urbanisation (BPS 2014), and a rise in household incomes. The

Indonesian human population and cattle population are both concentrated on the central island of Java. However, the capacity to increase beef production in this region is limited by the lack of cost-effective feed stocks. Hence, there are significant prospects for provincial areas to increase beef production and their involvement in the national beef supply chain (Waldron *et al*. 2013). In particular, East Nusa Tenggara is one province that could benefit greatly. It has the fifth highest beef cattle population in Indonesia (1.03 million in 2018; BPS 2018), but is also one of the poorest provinces, with high rates of poverty and food insecurity, especially amongst rural smallholders (BPS 2019). Although beef productivity is currently low in East Nusa Tenggara, production could be increased through better feeding, management and breeding systems.

Cattle kept by smallholder farmers in eastern Indonesia and elsewhere in Southeast Asia are typically fed low-quality diets based on crop residues (e.g. rice straw and maize stover) and native grasses with limited supplementation. These low-quality diets are often exacerbated by low feed availability later in the dry season, which has negative implications for reproduction and growth rates. Smallholder farmers require options for increasing the quantity and quality of forages in livestock diets, but these options need to be integrated with current food-production systems rather than replacing them. In particular, new forage or feed systems need to complement, rather than compete with, important staple grain crops such as rice and maize.

Forage legumes, in the form of tree shrubs or shorter lived herbaceous species, provide opportunities to increase the crude protein (CP) content of livestock diets (Jones *et al*. 2000), and can be fed fresh during the growing season, or harvested, dried and stored as hay for feeding during periods of feed or labour shortages. Previous research has demonstrated significant increases in liveweight gain (LWG) from feeding the tree legumes leucaena (*Leucaena leucocephala*) and sesbania (*Sesbania grandiflora*) (Dahlanuddin *et al*. 2014*a*, 2014*b*). However, tree legumes are not suitable in all regions or farming systems. Herbaceous legumes such as clitoria (*Clitoria ternatea*) and centrosema (*Centrosema pascuorum*) can be integrated into existing cropping systems to provide a high-quality feed for livestock (Oguis *et al*. 2019).

This paper examines the potential for herbaceous legumes to provide benefits to livestock productivity when integrated into crop–livestock systems in eastern Indonesia. We examine three niches where herbaceous legumes could be used in the current systems: (*i*) supplementation of cows to minimise loss of condition during the dry season, which contributes to extended inter-calving intervals and low turnoff rates; (*ii*) supplementation of unweaned calves to increase LWG and reduce mortality; and (*iii*) supplementation of weaner bulls to increase LWG. We examined whether these feeding strategies can increase livestock production, contributing to improvements in income from livestock without compromising yields of staple grain crops or utilising additional areas of land.

Materials and methods

On-farm and research station experiments were designed to test the response of different classes of cattle to the inclusion of herbaceous legumes in the diet in different production systems. In each experiment, legumes were provided to the farmers, but grown locally as part of engagement and demonstration activities. The experiments were conducted on the islands of West Timor and Sumba in East Nusa Tenggara province in eastern Indonesia. This region of Indonesia has a semi-arid tropical climate with highly variable rainfall. Average annual rainfall at Kupang in West Timor (2001–11) was 1310 mm and ranged from 1000 to 1800 mm. There is a strong wet season (December–March) when ~80% of rain falls, followed by a long dry season (April–November) with low and variable rainfall. Temperatures fluctuate little throughout the year, with average monthly maximums ranging from 32°C to 35°C and minimums ranging from 18°C to 24°C, August being the coolest month and October and November the hottest months.

All experiments were conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (NHMRC 2004) and were reviewed by the CSIRO (Expts 1–4) and University of Queensland (Expt 5) animal ethics committees.

Supplementation of cows during the dry season

The effect of supplementing cows of the Ongole breed (*Bos indicus*) with herbaceous legumes during the dry season was assessed in two on-farm experiments in different locations and years in Sumba. Cattle in Sumba are managed in large herds, free-grazing unimproved, common land during the day and penned at night for security. Pastures consist of low-quality native grasses, dominated by *Themeda* spp., with very low annual productivity (Fig. 1) (Rudolf *et al*. 1988; Bamualim 1996). The amount and quality of feed available varies throughout the year, with severe feed deficits late in the dry season (Rudolf *et al*. 1988; Bamualim 1996; Kana Hau and Nulik 2015).

Experiment 1

In 2015, 15 non-pregnant, non-lactating Ongole cows of similar liveweight (LW) and physiological status were selected from a larger herd in Melolo village to provide a representative subsample: mean age (± s.d.), 5 ± 2 years; LW, 221 ± 40 kg; body condition score (BCS, 1–5 scale), 2.3 ± 0.6. Five of these cows were randomly allocated to the legume supplement group, and the other 10 cows to the control group (no supplementation). Between August and November (14 weeks), all cows grazed together during the day as part of the larger herd and were penned at night in communal pens. Cows that received the legume supplement were penned as a separate group and were fed dried clitoria hay daily at ~10 g dry matter (DM)/kg LW, which was estimated to be adequate for maintenance of LW based on the energy requirements of Ongole cows (Syahniar *et al*. 2012; Antari *et al*. 2014*b*). Cows in the control group did not receive any feed overnight, which is standard practice for farms in this region.

Experiment 2

In 2016, 30 non-pregnant, non-lactating Ongole heifers (2.3 ± 0.8 years, 195 ± 35 kg, BCS 2.4 ± 0.5) were selected from a larger herd at Praipuluhamu village. Fifteen heifers

Fig. 1. Grasslands in Sumba consisting of low-quality, low-yielding native grasses. Images show the same site in November 2014 (dry season) and April 2015 (wet season). Photo credit: D. Mayberry.

were randomly allocated to the legume supplement group and provided with clitoria hay overnight, and the remaining 15 cows were allocated to the control group (no supplementation). Each group was managed as described for Expt 1, but this experiment ran for a longer period of 23 weeks from mid-July to December.

In both experiments, forage legumes were grown in the villages and cut by hand to 5 cm height above ground level at mid-flowering, sun-dried on a tarpaulin or concrete floor for 3–5 days, and compressed into bales that each contained ~10 kg DM. Farmers were asked to feed one bale of hay per five cows each night. No samples of the legume hay or grazed grasses were collected for analysis and individual or group intakes were not measured. In both experiments, cows and heifers were weighed monthly in the morning before being released to graze.

Supplementation of calves before weaning

Experiment 3

The impact of supplementation on calf mortality and LWG was investigated during an on-farm experiment at Oesao and Bipolo villages in Kupang District, West Timor, between September and December 2017 (16 weeks). In West Timor, Bali cattle (*Bos javanicus*) are managed in semi-intensive systems where maize stover, rice straw, crop stubbles and native grass are the main feed resources. Most cattle are tether-grazed or free-graze during the day, then are penned at night (Bamualim and Widahayati 2003).

Bali calves born between May and July (33 ± 10 kg LW) were randomly allocated to one of four treatment groups: control (no supplement, n = 16); legume hay (n = 13); clitoria hay plus cassava (n = 14); or a manufactured concentrate (n = 14). Treatments were allocated evenly across villages. Except for supplementary feeding, there was no change to management of the cattle used in this experiment. Calves grazed common land and crop stubbles during the day with their mothers, and all animals were penned at night. Calves were supplemented daily at 20 g DM/kg LW based on the recommendation of Jelantik *et al*. (2008*b*). The supplement was provided in a creep feeding system that only the calves could access. The amount of supplement for the calves was delivered to each farmer on a weekly basis and offered to the calves in approximately equal portions each day, with orts, if any, discarded. Calf LW was measured monthly, and the amount of supplement provided to each farmer was recalculated after each weighing. Feed orts were observed, but not weighed, and provision of supplements was considered to be *ad libitum*.

Clitoria was grown under irrigation, harvested by hand before flowering, and cured and conserved as described for Expts 1 and 2, with the exception that dried clitoria was chopped mechanically before baling. Subsamples of hay were collected from each bale and bulked before nutritional analysis (Table 1).

Dried and chopped cassava was purchased from local markets, ground to pass through a 2-mm sieve, and combined with the chopped clitoria hay before feeding, at a 2 : 1 legume : cassava ratio. Concentrate was manufactured based on the recipe used in Jelantik *et al*. (2008*b*), and contained cornmeal (35%), rice bran (26%), dried leucaena leaf meal (15%), fish meal (14%) and grass (10%).

Supplementation of growing bulls

Two experiments were conducted to assess the use of legumes for increasing LWG of growing Ongole bulls in Sumba and Bali bulls in West Timor. Across the eastern islands of Indonesia, a small but increasing number of cattle, particularly growing bulls, are penned all day and fed exclusively in a cut-and-carry system. Diets are usually based on native grasses and crop residues, although they may be supplemented with purchased concentrates if available.

Experiment 4

The growth rate of young Ongole bulls was assessed in a pen feeding trial at Milipinga Research Station, Sumba. Ten 18-month-old Ongole bulls (157 ± 12 kg, all BCS 2) were housed in individual pens for 11 weeks between May and July 2017. Bulls were allocated equally to one of two treatments (control or legume) on a stratified LW basis. All bulls were fed a diet of moderate- to low-quality roughage *ad libitum* to simulate farm feeding practices. For the first 5 weeks, this roughage was native grass, mainly *Themeda triandra* and *Sorghum nitidum*. As the dry season progressed, grass became increasingly unavailable, and for the second half of the experiment (Weeks 6–11) bulls were fed rice straw instead. Bulls in the control group were not provided with any additional feed, whereas those in the legume group were offered fresh clitoria at 20 g DM/kg LW in addition to the grass or rice straw, recalculated fortnightly after animal weighing. All bulls had *ad libitum* access to water during the experiment.

Clitoria was grown under irrigation, harvested the day before feeding and allowed to wilt overnight. Native grass was collected from grazing lands near the research station, and rice straw was purchased from nearby farmers. Feed was chopped by hand before feeding each morning then offered to bulls in two approximately equal portions in the morning and afternoon. Clitoria was fed at the same time as the grass or rice straw. Orts were collected each day before the morning feeding. Two days each week, orts were separated into feed types and weighed to calculate average daily feed intake.

Liveweight, hip height and BCS of bulls were measured every 2 weeks, in the morning before feeding. Subsamples of each feed type were collected monthly and air-dried, then stored before nutritional analysis (Table 1). Ovens were not available in Sumba for accurate measurement of DM content. Thus, DM intake (DMI) of bulls and the amount of legume offered daily was calculated by using DM values reported in the literature: clitoria, 25% DM (Nulik *et al*. 2013); native grass, 25.8% DM (Quigley *et al*. 2009); rice straw, 63.4% DM (Mayberry *et al*. 2014). Feed conversion ratio was calculated by dividing average DMI by average daily LWG.

Experiment 5

The growth rate of weaned Bali bulls grazing native pastures was compared with that of bulls supplemented with herbaceous legumes or leucaena in an on-farm experiment in Usapinonot, West Timor, between April 2008 and February 2009 (44 weeks). Sixteen Bali bulls (8.7 ± 2.1 months of age, 81 ± 14 kg LW) were randomly allocated to one of three treatments: control grazing (n = 5), grass + legume hay (n = 5), or grass + tree legumes (n = 6). Bulls in the control grazing group were kept under existing management practices and tether-grazed on areas of native pastures around the village. Bulls in the legume-supplemented groups were housed in individual stalls and fed a diet of native grasses *ad libitum* and an additional supplement of either clitoria, stylosanthes and centrosema hay, or fresh leucaena at 1.5 g DM/kg LW.day. The herbaceous legumes were grown locally, harvested before flowering, then air-dried and compacted into bales for storage. Leucaena was harvested daily and fed fresh.

Bulls were weighed every 2 weeks, and no samples of feed were collected for analysis.

Feed analysis

Dried samples were ground through a 2-mm screen. Organic matter was determined by combusting samples at 500–600°C for 2 h (AOAC method 942.05), total N was analysed using the Kjeldahl technique (AOAC method 976.06), and crude fibre was determined by the ceramic fibre filter method (AOAC method 962.09) (AOAC 2012). Gross energy was measured in a 6400 calorimeter (Parr Instrument Co., Moline, IL, USA) according to the manufacturer's operating instructions.

Table 1. Chemical composition of diets fed to unweaned Bali calves (Expt 3) and growing Ongole bulls (Expt 4)

	Calf-feeding experiment			Bull-feeding experiment		
	Clitoria hay	Clitoria hay + cassava	Concentrate	Fresh clitoria	Native grass	Rice straw
Organic matter (g/kg DM)	898	893	882	928	907	798
Crude protein (g/kg DM)	239	192	233	226	30	41
Crude fibre (g/kg DM)	276	227	109	331	325	311
Gross energy (MJ/kg DM)	16.2	15.7	16.0	16.9	15.5	13.3

Statistical analyses

In Expts 1 and 2, treatment effects on LW and BCS were compared by using *t*-tests in GENSTAT 19th Edn (VSN International, Hemel Hempstead, UK). In Expt 4, *t*-tests were also used to compare treatment effects on LW, hip height and feed intake. In Expts 3 and 5, treatment effects on LWG and feed intake were compared by using analysis of variance with pairwise comparisons. Village was used as a blocking effect in Expt 3. Significance level was set at $P = 0.05$.

Amount of land required to produce legumes for livestock

The amount of land required to produce enough legume for each feeding strategy described above was calculated based on measured yields of clitoria grown in permanent stands (3.5–6 t DM/ha dryland, 6–9 t DM/ha irrigated) or integrated into cropping systems (0.5–4 t DM/ha dryland, 4.5–7.5 t DM/ha irrigated) (L. Bell, unpublished data). We calculated feed required for supplementation of mature cows at 10 g DM/kg LW for a 6-month dry-season period; creep-feeding of unweaned calves at 20 g DM/kg LW for 6 months; and feeding growing bulls a diet based on legumes at 20 g DM/kg LW throughout the year. The LW of each cattle class was based on average values from Mayberry *et al*. (2016).

Results

Supplementation of cows during the dry season

In Expt 1, differences in average daily LWG between the non-supplemented cows (–0.05 kg/day) and those fed clitoria hay (0.02 kg/day) were small and not statistically significant (Table 2), possibly due to the small number of animals used in the experiment. Over the 14 weeks of monitoring, cows in the non-supplemented group lost an average of 4.5 kg LW and 0.3 BCS units, whereas those fed legume hay gained 2.4 kg LW and maintained BCS over the same period.

Larger differences were observed in Expt 2. Heifers in the non-supplemented group gained 7.3 kg LW and maintained BCS over 23 weeks with an average LWG of 0.04 kg/day (Table 2). Heifers provided with clitoria hay had significantly ($P < 0.05$) higher LWG (0.15 kg/day), gaining 24.8 kg LW and 0.6 BCS units over the same period.

Table 2. Average daily liveweight gain (LWG) and change in body condition score (BCS) of Ongole cows (Expt 1, 14 weeks) and heifers (Expt 2, 23 weeks) during the dry season in Sumba

Within a row, means followed by a different letter are significantly different at $P = 0.05$; s.e.m., standard error of the mean

	Diet		s.e.m.	*P*-value
	Grazing only	Grazing + legume hay		
	Experiment 1			
Av. LWG (kg/head.day)	–0.05	0.02	0.02	0.064
Change in BCS	–0.3	0.0	0.1	0.196
	Experiment 2			
Av. LWG (kg/head.day)	0.04a	0.15b	0.01	<0.001
Change in BCS	–0.1a	0.6b	0.1	0.003

Supplementation of calves before weaning

In Expt 3, supplementation reduced mortality rates in calves provided with a supplement (0–8% mortality) compared with non-supplemented calves (25%) (Table 3). Four calves died in the control group, one calf died in each of the clitoria hay + cassava and concentrate groups, and there were no deaths in the legume hay group. No definitive cause of death was identified, but the dead calves were all observed to be thin with diarrhoea before death. All deaths occurred between late September and mid-October, which is the late dry season in this region.

The LWG of calves was significantly increased in response to clitoria hay or clitoria hay + cassava supplementation (Table 3). The non-supplemented calves showed negligible or very slow growth rates, whereas the calves supplemented with legume hay grew at >0.2 kg/day over the experimental period. There was no significant difference in LWG between non-supplemented calves and those supplemented with the concentrate. There was also no difference in average daily LWG between male and female calves.

Supplementation of growing bulls

In Expt 4, Ongole bulls consuming clitoria had higher LWG and greater change in BCS and hip height than bulls fed only native grass or rice straw. Feeding clitoria increased average daily LWG by 0.3 kg/day, with supplemented bulls weighing 26 kg more than bulls fed only native grass and rice straw at the completion of the 11-week experimental period. Total feed intake and intake of CP and gross energy was higher in bulls supplemented with clitoria than those fed only native grass and rice straw, with a higher feed conversion efficiency (kg DMI/kg LWG) (Table 4). Bulls consumed most, but not all, of the clitoria offered.

In Expt 5, Bali bulls supplemented with legume had significantly ($P < 0.01$) higher LWG (0.25 kg/day) than non-supplemented bulls (0.05 kg/day). There was no significant difference in LWG between bulls supplemented with leucaena (0.28 kg/day) or herbaceous legume hays (0.22 kg/day).

Discussion

The results from experiments presented in this paper represent real-world, smallholder farming systems and illustrate

Table 3. Mortality rate and average daily liveweight gain (LWG) of unweaned Bali calves supplemented with clitoria hay, clitoria hay + cassava, or a manufactured concentrate

For LWG, means followed by the same letter are not significantly different at $P = 0.05$; s.e.m., standard error of the mean

Supplement type	*n*	Mortality (%)	LWG (kg/head.day)
None (control)	16	25	0.10a
Concentrate	14	8	0.14ab
Clitoria hay	13	0	0.21bc
Clitoria hay + cassava	14	8	0.24c
s.e.m.			0.01
P-value			<0.001

Table 4. Average daily feed intake and growth of Ongole bulls fed native grass or rice straw *ad libitum*, with or without legume (clitoria) for 11 weeks

Within a row, means followed by a different letter are significantly different at $P = 0.05$; s.e.m., standard error of the mean. LW, Liveweight; LWG, LW gain

	Diet		s.e.m.	*P*-value
	Native grass or rice straw	+ Legume		
Total feed intake (g DM/kg LW.day)	20.2a	27.5b	1.0	<0.001
Clitoria intake (g DM/kg LW.day)	–	19.1	0.1	
Grass and rice straw intake (g DM/kg LW.day)	20.2a	8.41b	2.0	<0.001
Crude protein intake (g/kg LW.day)	0.72a	4.60b	0.7	<0.001
Gross energy intake (MJ/kg LW.day)	0.29a	0.44b	0.02	<0.001
Feed conversion ratio (kg feed intake/kg LWG)	21.6a	9.7b	2.2	0.002
LWG (kg/day)	0.16a	0.50b	0.06	<0.001
Change in body condition score (1–5 scale)	0.4	0.6	0.1	0.195
Change in hip height (cm)	3.6a	4.8b	0.3	0.004

multiple potential roles for herbaceous legumes such as clitoria to increase livestock productivity in crop–livestock systems of eastern Indonesia. Similar potential applications are also likely in other systems throughout Southeast Asia. Traditional livestock diets in these systems are typically low in CP and metabolisable energy (ME), limiting growth, reproduction and survival. As demonstrated here, herbaceous legumes provide an additional source of CP that can be strategically fed to different classes of livestock to overcome specific production issues and contribute to increased productivity and income generation. Through integration of herbaceous legumes into existing cropping systems, high-quality livestock feed can be grown without compromising yields of staple grain crops or utilising additional areas of land.

Prospects for improving livestock productivity in eastern Indonesia

Our results show a clear role for herbaceous legumes to increase cattle reproduction by maintaining the LW and BCS of cows during the dry season. Low reproduction rates in both Ongole and Bali cows have been the primary target of recent government programs and policies aimed at increasing beef production in Indonesia. For example, the national UPSUS SIWAB Program (Ministry of Agriculture Regulation No. 48/PK.210/10/2016, https://ditjenpkh.pertanian.go.id/userfiles/regulasi/479dbe8da46873285a8f78f029c899e6.pdf) aims to increase cattle numbers through improved cow nutrition and management. Although our project did not measure reproduction following legume supplementation, links between cow condition and conception are well established (Montiel and Ahuja 2005). It is not unreasonable to suggest that feeding legume hay to cows to maintain, or even increase, LW during periods of nutritional stress will contribute to improvements in conception rates and shorter inter-calving intervals. Our results provide an on-farm validation of previous pen-feeding studies showing that small amounts of legumes provide sufficient energy and CP for maintenance of LW of cows fed otherwise low-quality diets (Syahniar *et al.* 2012; Antari *et al.* 2014*a*, 2014*b*). Higher levels of supplementation may be required to maintain condition of cows during periods of higher energy demands, such as late gestation and early lactation, but could play an important role in reducing loss of condition during those times. Herbaceous legumes could also be fed to weaned female calves to increase growth rates and reduce the age of puberty, further contributing to increased lifetime productivity (D'Occhio *et al.* 2019).

Our research also demonstrated a role for herbaceous legumes in contributing to increased beef production through increased calf survival and liveweight gain. The mortality rate of 25% for non-supplemented calves in our experiment was at the lower end of previously reported values of 22–48% for the Kupang district (Talib *et al.* 2003; Jelantik *et al.* 2008*a*). By comparison, mortality rates of unweaned calves were reduced to ≤8% in all groups of calves provided with a supplement, indicating that under conditions of severe feed shortages, provision of any additional feed can increase calf survival. Average LWG of supplemented unweaned calves in our experiment was similar to that reported by Jelantik *et al.* (2010) of 0.17 kg/day for calves in Kupang district offered a concentrate supplement, but lower than values for Bali calves of similar age elsewhere in Indonesia; for example, Mayberry *et al.* (2016) report an average LWG of 0.31 kg/day for unweaned Bali calves in Lombok. Jelantik *et al.* (2010) observed differences in LWG of calves between districts in West Timor and hypothesised that this could be due to a regional lack of feed available to grazing cows or differences in animal management, possibly arising from shortages in household labour. Thus, it is possible that providing herbaceous legumes to Bali cows as well as calves, while still utilising the creep-feeding system ensure that calves have unrestricted access to feed, would result in further improvements in LWG. Improvements in animal housing and husbandry made to reduce possible production losses from disease may also improve growth rates. Even at the modest growth rates recorded here, calves fed legume hay would be substantially heavier at weaning than their non-supplemented counterparts, with an ~20 kg LW advantage following 6 months of supplementation. If these growth rates were maintained, they would reach slaughter weight (average

260 kg LW; Dahlanuddin *et al*. 2014*b*) in roughly half the time of non-supplemented bulls.

Feeding herbaceous legumes also increased the LWG of older Bali and Ongole bulls by 300–500%, though LWG remained below the genetic potential for animals of similar age. Pen-feeding studies indicate that both weaned Bali and Ongole calves of age <1 year gain 0.6 kg/day when fed diets containing adequate CP and ME (Antari *et al*. 2014*c*; Quigley *et al*. 2014), and LWG of more mature bulls can be >0.8 kg/day (Antari *et al*. 2014*c*; Dahlanuddin *et al*. 2014*b*). In our studies, the CP content of diets consumed by the bulls was estimated to be above the minimum required to maximise LWG for both breeds (13% CP for young Ongole bulls and 10% CP for young Bali bulls; Antari *et al*. 2014*c*). Thus, we infer that a source of additional ME is required to increase LWG further. Extra energy could be used both to utilise any excess rumen degradable protein, and to increase overall ME intake (Harper *et al*. 2019). This has been demonstrated in pen-feeding trials and both grazing and cut-and-carry systems using tree legumes, with increases in total DMI and LWG in cattle fed leucaena or sesbania plus rice bran or maize bran (e.g. Quigley *et al*. 2009; Dahlanuddin *et al*. 2014*a*, 2014*b*).

Comparison of herbaceous legumes with other supplementation options

Herbaceous legumes such as clitoria can be fed alone, or in conjunction with other energy or protein supplements, to improve the feeding value of livestock diets. The key advantage of legumes over concentrates or other purchased feeds is that they can be home-grown with little input or cost. By comparison, the cost of concentrate feeds makes them inaccessible for cash-poor smallholder farmers, and they are not always readily available in the market. These barriers to supplementary feeding are clearly illustrated in the example of calf supplementation in West Timor. There has been no uptake of feeding concentrate to calves despite large potential improvements in calf growth and survival rates (Jelantik *et al*. 2008*b*). With the right support for smallholders and consistent access to seed stock, the use of legumes for feeding of calves and other livestock should be more widely adoptable. In a similar project in Laos, herbaceous legumes used in a rice–legume system were predicted to reach a peak adoption of 54% within 6 years (Monjardino *et al*. 2020). Similar adoption rates should be achievable in eastern Indonesia.

In addition, feeding of purchased concentrates may not provide any production advantage over home-grown feeds. In the calf creep-feeding experiment (Expt 4), higher LWG was observed in calves supplemented with clitoria hay (with or without additional cassava, 0.23 kg/day) than in calves fed the concentrate supplement (0.14 kg/day). This is consistent with the findings of Quigley *et al*. (2009), who reported that supplementing Bali calves with tree legumes resulted in LWG similar to that of calves supplemented with rice bran and copra meal. However, feeding tree legumes provided a bigger increase in revenue over cost. Similarly, in an experiment with Brahman cows, Antari *et al*. (2014*a*) found no LWG advantage in using expensive, purchased supplements such as onggok (a cassava by-product) compared with tree legumes, which can be grown on farm for little or no cost.

Feed quality and therefore LWG of cattle fed herbaceous or tree legumes are generally comparable. This is illustrated in the results from the Bali bull feeding trial in Usapinonot (Expt 5), in which there was no significant difference in LWG between animals supplemented with clitoria and with leucaena. The biggest difference between herbaceous and tree legumes is how they are integrated into farming systems. Tree legumes such as sesbania and gliricidia (*Gliricidia sepium*) are most commonly planted as living fences around homes and cropland, providing small but consistent amounts of fresh green feed throughout the year. In more specialised production systems, as are developing in Lombok and Sumbawa (Dahlanuddin *et al*. 2014*b*, 2017), plantations of leucaena or sesbania are grown to support bull-fattening enterprises. This provides higher amounts of biomass but is not compatible with cropping, and trees take 12–18 months to become established before the first harvest. By comparison, herbaceous legumes can be harvested within months of planting, and can be integrated into existing maize and rice production systems by sowing in a relay or rotation. Where land is available, they can also be sown as permanent stands, with Gabb (2017) indicating this can be a profitable option for commercially orientated farmers with larger herds and land areas.

Fit of legumes in farming systems

Although some smallholders have specialised cow–calf or growing and fattening operations, many keep multiple types of cattle. Given the small land size of many households in Indonesia and throughout Southeast Asia, most farmers will not be able to grow enough legume to supplement all of their livestock and will have to make management decisions about which livestock class will receive the feed legumes (i.e. unweaned calves, growing animals or cows of reproductive age). Feeding strategies will be influenced by a range of factors including production system, household labour resources, livestock prices and local market demand (Gabb 2017); however, our research provides some general indications of how herbaceous legumes can be used in smallholder cattle-production systems.

Herbaceous legume biomass production and, hence, availability for livestock feeding is greatly influenced by the way in which it is used in the farming system and by the seasonal conditions, which induce annual variability in the results. Permanent legume stands are best suited to systems focused on the growing and fattening of bulls (Table 5), which have high nutritional demands but are also more likely to fetch good market prices. Clitoria grown as a perennial in a multi-year stand has the greatest potential annual biomass production because the establishment phase, when the large root system needs to be developed, is not required, and the crop can access a greater proportion of the rain that falls over the year. The use of permanent stands requires additional land that is either unutilised or is retired from staple crop production; this has potential implications for household

Table 5. Indication of the area of legume required to support different livestock types under the proposed feeding systems

Clitoria biomass yields are average values from experiments and village demonstrations in East Nusa Tenggara (L. Bell, unpublished data). Areas of legume required are rounded to the nearest 0.1 ha. LW, Liveweight; LWG, LW gain

Features of livestock feeding system	Livestock type: Mature Ongole cow	Mature Bali cow	Growing Ongole bull	Growing Bali bull	Unweaned Bali calf
Animal LW (kg)	340	220	250	150	50
Legume feeding rate (g DM/kg LW.day)	10	10	20	20	20
Purpose of feeding legume	Maintain LW during dry season		Increase LWG		Increase LWG and survival
Proposed feeding period (days/year)	180	180	365	365	180
Forage legume required per year (t DM/head)	0.6	0.4	1.5	1.1	0.2
	Legume planting area required (ha) for each livestock × production system type				
Legume production system and indicative yields:					
Dryland permanent stand (3.5–6 t DM/ha)	0.1–0.2	≤0.1	0.2–0.4	0.2–0.3	≤0.1
Dryland relay–rotation (0.5–4 t DM/ha)	0.2–1.2	0.1–0.8	0.4–2.9	0.3–2.2	≤0.4
Irrigated permanent stand (6–9 t DM/ha)	≤0.1	≤0.1	0.1–0.2	0.1–0.2	≤0.1
Irrigated relay–rotation (4.5–7.5 t DM/ha)	≤0.1	≤0.1	0.2–0.3	0.1–0.2	≤0.1

food security (Gabb 2017). It also requires a greater level of agronomic management such as weed control.

Legumes grown as a companion crop in a relay or at the same time as a maize have much lower forage biomass production potential than permanent stands as a result of greater competition for resources during the growing season and a shortened growing season before the onset of the dry season. However, this system can enable additional forage to be provided without replacing critical staple or cash crops in the farming systems. For farmers with small land areas, forage production in relays is unlikely to be high enough to support growing or fattening bulls unless the farmer has access to other high-quality feeds such as tree legumes or crop by-products. However, integrated systems do provide sufficient biomass to improve cow reproduction and/or increase the survival and LWG of young calves (Table 5), so are very suitable for improving cow–calf production. Forage biomass production can be significantly increased through irrigation, particularly during the early dry season. This is particularly relevant when the legumes are grown in paddy rice areas where supplementary irrigation water is often available.

Although herbaceous legumes can be fed year-round, we suggest that the greatest benefits will be from feeding to cattle during the late dry season and early wet season when nutritional shortages are widespread and most acute. For example, previous research has shown that less feed is required to maintain cow LW and BCS, rather than trying to regain LW following a period of undernutrition (Antari *et al*. 2014*b*). Alternatively, legumes could be used to increase LWG of growing bulls before the dry season so that they can be sold before feed becomes limiting.

Conclusions

Results from these feeding studies demonstrate how the strategic use of herbaceous legumes could increase livestock production in eastern Indonesia through increased reproduction, survival and LWG. Our research highlights that while herbaceous legumes can provide a valuable feed resource for livestock, particularly during the dry season, improved feeding alone is not enough to maximise livestock production. Importantly, our data reflect real-world scenarios, providing an on-farm validation of more controlled experiments reported in the literature. The integration of herbaceous legumes into existing crop–livestock systems could help to close productivity gaps in smallholder settings in Indonesia, and elsewhere in Southeast Asia where livestock production is tightly integrated with crop production and farmers need additional options to improve animal nutrition. These systems could contribute to meeting the rising demand for beef in low- and middle-income countries and allow smallholder farmers to capitalise on opportunities to participate in a national beef value chain.

Conflicts of interest

The authors declare no conflicts of interest.

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