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Final report

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2 Executive summary

East Nusa Tenggara (ENT, Nusa Tenggara Timur) is one of the poorest of Indonesia's provinces with high rates of poverty and food insecurity especially amongst rural small-holders. Intensification of beef production provides an opportunity to increase income generation, but beef cattle production is limited by unreliable and low-quality feed sources, particularly during the dry season. Yields of staple cereal crops (maize and rice) are low due to poor crop nutrition. Integration of forage legumes into farming systems has been identified as an option to improve nitrogen supply and yields of staple cereal crops (maize and rice) and nutrition of ruminant livestock during the dry season.

The project set out to research further the value proposition and fit for integrating herbaceous forage legumes into small-holder crop and livestock systems across ENT, Indonesia. This was done in 5 research nodes working with over 14 villages in the regions distributed across different agro-ecosystems across ENT. During the project 32 on-farm and field experiments have tested the potential benefits and trade-offs for different methods of integrating legumes with cereal crops, quantified the benefits of legume feeding in different livestock systems, and developed and tested locally-relevant management recommendations on the agronomy and seed production of forage legumes.

Clitoria ternatea has proven the most resilient and adaptable forage legume for use in association with cropping systems in ENT. Forage establishment and cutting management were shown to be critical to maximising legume productivity but labour inputs required are important constraints. Lower-labour options can be used effectively without dramatically compromising productivity. Local seed production is critical for ongoing use of herbaceous forage legumes, and our research has refined locally relevant recommendations for agronomy for seed production methods and processing.

We have demonstrated that significant grain yield benefits can be provided to subsequent crops where legumes are grown in rotation with maize or rice. Grain yields have been increased by 50% (1.4-1.6 t/ha) where legume was cut and removed, and by 90% (2.6-2.8 t/ha) where legume biomass was retained – the legume provides the equivalent of 100-150 kg of urea fertiliser. Legumes can also be grown in mixtures with low density maize crops with minimal risk of reducing grain yields.

Providing legumes as supplements to cattle have significant benefits for livestock productivity in various production systems. They can be used at low % of diets (0.5% of body weight) to reduce liveweight losses during the dry season in Ongole cows with benefits for increasing reproduction rates. Supplementing Bali calves through creep feeding systems can increase calf growth rates and reduce calf mortality significantly at lower cost than expensive concentrates. Finally, large increases in growth rates of growing cattle can be achieved (0.3-0.5 kg LW/d higher) when legumes are provided.

Socio-economic research using whole-farm bioeconomic modelling and participatory on-farm evaluation has found that livestock-oriented farmers with available land resources will benefit most from forage legumes. Potential increases of farm income of 6-7 M IDR/year (up to 30%) were possible. Where legumes have been trialled, we have seen reduced labour burden for women and labour inputs required were a clear driver for adoption.

Overall the project has demonstrated the wide potential for forage legumes to augment farming systems in ENT. Active involvement of farmers, particularly women, farm advisory networks and high schools in testing forage legumes has encouraged early adoption. This is evidenced by increasing demand for seed, evolving farmer-to-farmer seed and forage trading, emerging farmer champions, and wider promotion from government and non-government extension services through their livestock development programs. We have developed farmer-friendly extension materials, trained many next-users of our information, and supported seed production and distribution in the region, but these services need to continue to further promote wider adoption of herbaceous forage legumes in the region.

3 Background

East Nusa Tenggara (ENT) is one of the poorest of Indonesia's provinces with around 60% of the population living in poverty (<US$2) and over 40% of households are food insecure; this rate is higher in those deriving income primarily from agricultural activities (FAO *et al*. 2010). The cereal staples maize and rice are the most important food crops cultivated in ENT, but household self-sufficiency is limited by low use of fertilisers, especially in upland areas, combined with small areas of cropped land. This project set out to validate the potential of using herbaceous (i.e. non-woody) legumes to improve the livelihoods and food security of poor small-holder crop and livestock producers in this region. It was hypothesised this could be done via the intensification of livestock production systems, more effective use of land, labour and water resources, and improved crop nutrition with co-benefits for improved staple crop production. Current Indonesian policies and activities are encouraging increases in beef production in this region of Indonesia, and this project addresses the critical issue of forage supply and quality which is known to currently constrain beef production.

Beef production systems in eastern Indonesia range from extensive free grazing of communal feed resources, through to intensive cut and carry systems based on locally available forages, crop residues and agricultural by-products. In the more extensive systems such as found on the island of Sumba, large herds of Ongole (*Bos indicus*) cattle free graze common land during the day and are penned at night for security. The amount and quality of feed available varies throughout the year, with feed deficits and animal losses most pronounced late in the dry season (Bamualim 1996; Kana Hau and Nulik 2015; Rudolf *et al*. 1988). The loss of liveweight (LW) and body condition score (BCS) of cows during this period contributes to extended inter-calving intervals and low turnoff rates. Rudolf *et al*. (1988) showed that improving the quality of native pastures through oversowing of legumes and application of fertiliser can reduce losses of cattle LW during the dry season. However, management of communal pastures is difficult, and current cattle production systems in Sumba are still characterised by production losses during the dry season.

In West Timor, Bali cattle (*Bos javanicus*) are managed in semi-intensive systems where maize stover, rice straw and native grass are the main feed resources. Most cattle are tether-grazed or free-graze during the day, then penned at night (Bamualim and Widahayati 2003). One of the biggest limitations to cattle production in this area is the low survival rates of calves, especially those born in the middle of the dry season (June to August), when both the quantity and quality of feed for cattle is declining. Surveys of cattle production in East Nusa Tenggara report calf mortalities of up to 48% during this period (e.g. Jelantik *et al*. 2008a; Talib *et al*. 2003). Jelantik *et al*. (2008b) have demonstrated that supplementing Bali calves with a manufactured concentrate based on locally available sources of energy and protein (cornmeal, rice bran, leucaena leaf meal, fishmeal, grass hay) prior to weaning substantially reduces calf mortality and increases LW gain (LWG). However, this strategy has not been adopted by farmers due to the prohibitive cost of purchasing concentrate feeds.

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. LWG of these growing animals is limited by the quality and quantity of feeds offered, and consistently below the genetic potential of the breeds. For example, studies of current practice commonly achieve growth rates of only 0.1-0.3 kg/day for weaned Bali cattle (Priyanti *et al*. 2010) and <0.2 kg/day for young Ongole bulls (Kana Hau and Nulik 2015). Pen feeding studies indicate that both weaned Bali and Ongole calves <1 year old can gain 0.6 kg/day when fed diets containing adequate crude protein (CP) and metabolisable energy (ME) (Antari *et al*. 2014c; Quigley *et al*. 2014). LWG of more mature bulls can be in excess of 0.8 kg/day (Antari *et al*. 2014c; Dahlanuddin *et al*. 2014), hence there is significant potential to increase growth rates and reduce time to market though improved feeding of these growing animals.

Forage legumes in the form of tree shrubs or shorter-lived herbaceous species provide opportunities to increase CP in 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 LWG from feeding leucaena (*Leucaena leucocephela*) and sesbania (*Sesbania grandiflora*) (Dahlanuddin *et al*. 2013; Dahlanuddin *et al*. 2014). However, tree legumes are not suitable in all regions or farming systems. Herbaceous legumes such as *Clitoria ternatea* (clitoria) and *Centrosema pascuorum* (Centro) can be integrated into existing cropping systems to provide a high-quality feed for livestock (Oguis *et al*. 2019).

The integration of legume crops can also provide biological N inputs with the potential to improve N supply for cereal grain crops without some of the challenges faced by small-holder farmers for using inorganic nitrogen fertilisers (Giller and Cadisch 1995). The organic N in legumes releases N slowly, so is less prone to losses and can improve synchrony of supply and demand to crops. This can be particularly important in highly variable semi-arid environments, where it is difficult to match fertiliser inputs to inconsistent crop demand in different seasons. There is often unused soil water available at the end of the wet season cereal crops, which could be used to grow legume forages during the dry season if they were sown as a relay into maize prior to harvest (Dalgliesh *et al*. 2008). While grain legumes may be preferred in many crop-dominated areas, forage legumes providing high quality feed for livestock offer alternative legume options in mixed crop-livestock farming systems common in the semi-arid tropics. Alternatively, forage legumes could replace a cereal crop and grow for a longer period over the wet season before rotating back to cereal crops. A selection of legume forage species have been found to be adapted and are suitable to fit into farming systems as short-term rotation crops in eastern Indonesia. Clitoria, Centro and *Lablab purpureus* (Lablab) have shown significant production potential in Indonesia and have been successfully used in rotations with crops in semi-arid tropical and subtropical locations in Australia (Cullen and Hill 2006; Whitbread and Pengelly 2004; Cameron 1996).

While these integrated forage legume-cereal crop systems offer significant potential, there is limited evidence of the potential production of forage legumes when used in these ways or the benefits for subsequent cereal crop productivity in tropical environments. Most studies conducted in the tropics and subtropics of Australia have found increased N supply, growth and grain yields of subsequent crops following tropical forage legumes compared to following a previous cereal crops (Armstrong *et al*. 1997, 1999, Bell *et al*. 2017, Jones *et al*. 1996; Traill *et al*. 2018). In the semi-arid tropics of the Northern Territory, maize crops following a Verano stylo (*Stylosanthes hamata*) pasture ley increased crop biomass and N uptake by 50-300% compared to following a grass pasture, and increased subsequent crop uptake by 30 kg N/ha the equivalent of > 60 kg N fertiliser applied (Jones *et al*. 1996). Similarly, in central Queensland, grain yield and biomass of unfertilised wheat and grain sorghum crops were increased by over 150%, accompanied by an increase in grain protein, when they were sown after tropical forage legumes compared to following grain cereal crops (Armstrong *et al*. 1997; 1999). The legumes provided between 40 and 80 kg of fertiliser N equivalents to the subsequent crops. In these studies, the benefits of additional N provision from the forage legume rotation lasted more than 1 year (up to 3 years) (Jones *et al*. 1996; Armstrong *et al*. 1997; 1999). However, in these previously mentioned studies the higher yield responses were where forage legume biomass was retained and the removal of this for forage reduces the N supply to subsequent crops (Traill *et al*. 2018). Nonetheless, even when legumes are removed they can provide useful additional N supply of 30-40 kg of equivalent fertiliser-N and sometimes significantly increase subsequent crop yields (Bell *et al*. 2017).

This project builds on a previous initial proof-of-concept project (LPS/2006/003) which identified the potential for herbaceous forage legumes in West Timor, Indonesia. Through modelling and field experimentation, this work identified potential for herbaceous forage legumes to be grown following a cereal grain crop to take advantage of soil moisture at the start of the dry season. It was found that forage legumes would be a good option to fit into this niche in order to utilise unused water and to provide benefits to both the cropping and livestock components of farming systems. The risks and benefits of this intervention were not examined widely. A small range of forage legumes were found to be well adapted across a range of environments. Three species showed wide adaptation and were preferred by local farmers; Clitoria (clitoria; *Clitoria ternatea cv.* Milgarra), Centro (*Centrosema pascuorum cv.* Cavalcade) and lablab (*Lablab purpureus cv.* Highworth). However, several issues related to the agronomic management of these forages (e.g. harvesting regime, sowing dates, nutrition, diseases/pest pressures) were identified that required further work. Some preliminary work also demonstrated that forage legumes could be integrated into cereal cropping systems in relay or rotation, but crop responses were variable and dependant on the level of in-season legume leaf drop and harvesting intensity. Evidence of N fixation, factors affecting this and the potential inputs from forage legumes under typical farmer harvesting practises were required to determine the likely benefits for subsequent crops. Initial studies feeding legumes in diets of cattle and goats found that feeding legumes as a component of animal diets was beneficial for increasing growth rates of growing animals. However, the potential for forage legumes to be fed to other livestock classes, where benefits from overcoming key nutritional constraints may be larger requires testing. Initial work also demonstrated potential to produce seed to meet future potential demand in-country. Successful seed production by local extension organisations has begun but results have been variable. Information on the environments most suitable for seed production and how to manage the legumes to optimise seed production are required. Hence, this project set out to add further evidence on the value proposition for using legumes in the farming systems of eastern Indonesia and to address critical knowledge gaps identified in the previous work. Hence, additional research and on-farm testing was undertaken to develop the information required to provide more confidence in this technology and facilitate subsequent adoption and uptake of the technology in other development programs in eastern Indonesia. The project built on previous research and relationships in West Timor and established new sites in Flores and Sumba to establish 5 research nodes in the regions of Kupang and Timor Tengah Seletan, West Timor; Ende and Nagekeo, Flores; and East Sumba (see Figure 2).

Plate 1. Through integration of legumes with staple cereal crops the project aimed to enhance beef cattle productivity at the same time as improving N supply to maize or rice crops. Photos courtesy of Neal Dalgliesh (left), John Dida (middle), Skye Traill (right).

4 Objectives

This project's overall goal was to demonstrate the potential and establish the value proposition for integrating forage legumes, that is quantify their potential benefits on livelihoods and limitations, in small-holder crop and livestock systems in East Nusa Tenggara, Indonesia.

Objective 1: Develop forage legume use and management recommendations that optimise their growth, quality and impacts on subsequent crops

Field experimentation was undertaken across the 5 target regions to examine key management questions such as soils and locations most favourable for growing forage legumes, cutting management (height and frequency), row spacing, sowing time and fertilisation that maximise their biomass production and/or quality. In new regions (e.g Sumba), initial experiments focused on validating the performance of various forage legumes in for rotations in cropping areas and for introduction into grasslands. A set of experiments investigated the potential N contribution from forage legumes to subsequent cereal crops. Data was obtained from experiments to develop APSIM parameters to model production of forage legumes that enabled climate risk and alternative management options to be explored, as well as provided input into whole-farm modelling.

Objective 2: Determine target timing and livestock classes to feed forage legumes to maximise their benefits in livestock production systems.

Livestock feeding experiments and demonstrations aimed to determine the changes in animal growth, survival and condition from feeding forage legumes at different times of the year (i.e. wet season, early dry season and later dry season) and to different livestock classes. These experiments mainly targeted beef production systems but the role for feeding to other livestock (e.g. goats) was also considered in areas where they are more common (e.g. Ende, Flores).

Objective 3: Quantify the impact on profitability and livelihoods and identify key drivers and limitations for integrating forage legumes across diverse farming systems in ENT.

Farm surveys described the diversity of farm types across the region and helped identify those farms with greatest prospect for using forage legumes. Whole-farm bio-economic modelling using the IAT analysed economic, risk and production implications and possible constraints of integrating forage legumes into livestock production systems. Participatory assessments of the benefits, constraints and proposed role for the forage legumes were conducted with diverse groups with different livestock systems, land and resource availability.

Objective 4: Understand key physiological and agronomic influences on legume seed production to identify target production environments and best-bet seed production practices in eastern Indonesia.

Experimental activities were undertaken in Australia and a range of locations in Indonesia to understand the physiological and environmental drivers of phenology and seed production for a range of species and hence identify locations where seed production could be most appropriate. Management techniques such as trellising and cutting were examined to optimise seed crop management. On-going training and support for further development of seed multiplication and long-term legume seed supply in the region were initiated.

Objective 5: Improve knowledge and skills in legume-based crop and livestock systems and systems research approaches in Indonesian research and farming communities.

Through collaborative research the project further developed farming systems research skills within BPTP and collaborating organisations including the use of production/economic analysis tools (IAT, APSIM) and skills in scientific publication and presentation. Through the development of curriculum and mentoring of teachers, and involvement of high schools in each district and regional Universities in experimental activities the project had a wide-reaching impact on educating communities on the benefits of forage legumes and improved farming systems. Project activities and junior research staff were linked with local agricultural extension staff to develop wider understanding of the project research findings and skills and knowledge of the use of forage legumes in farming systems.

Figure 1. Multi-disciplinary approach to testing the impacts of integrating forage legumes into crop and livestock systems in East Nusa Tenggara, Indonesia.

5 Methodology

The project targeted five research nodes distributed across different agro-environments and production systems in Eastern Nusa Tenggara (Figure 2):

- **Kupang, West Timor** is low-land area (<100 m above sea level) with predominant irrigated rice, dry season maize (and other crops) and Bali cattle breeding and fattening
- **Timor Tengah Seletan, West Timor** is cooler upland region (400-800 m above sea level) with predominant wet-season maize and a diversity of livestock enterprises
- **Ende, Flores** is a volcanic-mountainous region with much higher rainfall and more fertile soils than West Timor, with paddy rice and dryland maize but beef cattle production is less common.
- **Nagekeo, Flores** is a less mountainous region, hotter and drier than Ende, with high importance on beef cattle breeding and fattening
- **East Sumba** (Sumba Timur) is a much drier island with large areas of free grazing livestock with Ongole cattle mainly on predominantly native pastures growing on shallow and nutrient poor limestone plateau. Interspersed fertile areas are used for growing dryland maize and other food crops.

Previous research had focussed initially on West Timor, followed by some initial testing in limited environments on Flores but no previous work had been done on Sumba.

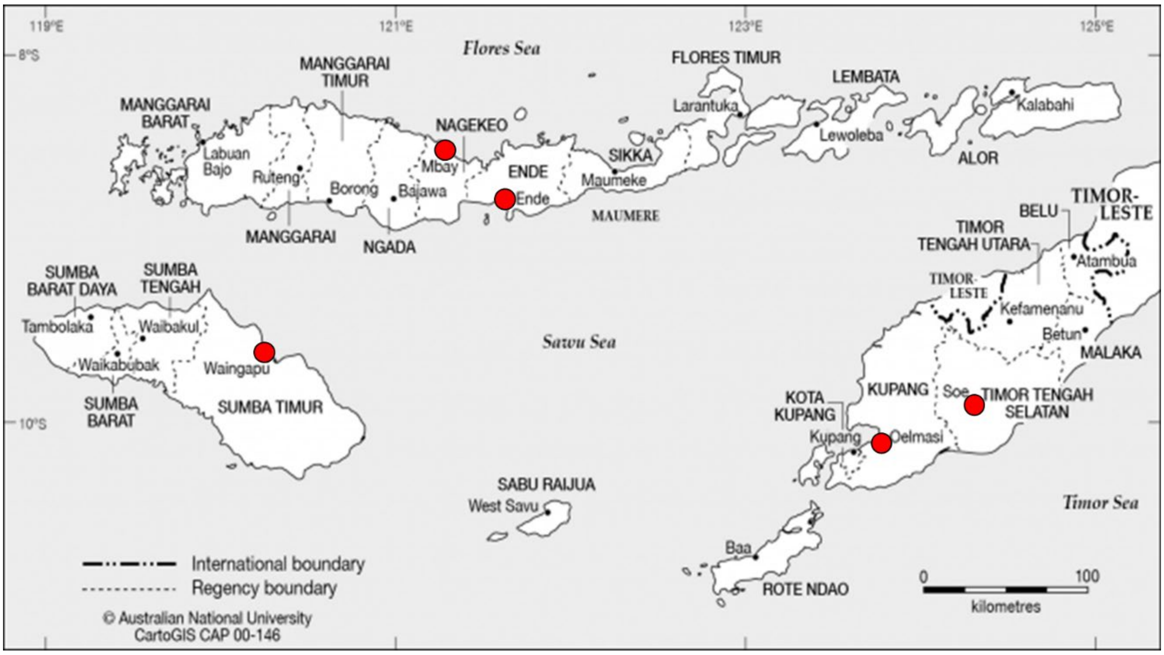


Figure 2. Map of East Nusa Tenggara with red dots indicating locations of research nodes (source: CartoGIS Services, College of Asia and the Pacific, The Australian National University).

Across these sites we conducted a series of 32 experiments designed to further quantify the value proposition for integrating forage legumes into the farming systems by examining:

- Locally relevant agronomic management practices that would result in more reliable or greater productivity of the forage legumes. Thirteen individual experiments across environments and years tested legume forage establishment approaches, cutting management and evaluated forage legumes in new environments.

- The implications for crops when integrated in different ways with different forage legumes via rotations, or intercrops or relays (where the crops and legumes are grown in a combination) and the influences of legume and crop management. Three multi-season experiments quantified forage legume production and subsequent maize and rice crop responses.
- The potential impacts or benefits of supplementing diets of different livestock classes with forage legumes compared to current management.
- Refinements to local seed production practices via testing how different environments (latitude and altitude), sowing dates and management (e.g. trellising) impact on the reproductive development and seed production in prioritised forage legumes

Table 1 outlines the list of experimental details, locations and seasons conducted over the life of the project. These issues were prioritised annually in response to annual feedback from local farmers and extension groups involved in the project. This saw experiments designed to respond to identified issues such as legume-maize intercrops, legume-rice rotations, Ongole bull fattening, labour-requirements for sowing and cutting, and live maize trellising for seed production. Evaluation sites in new regions, some initial seed production research and rotation experiments included a diversity of legume genotypes which had demonstrated some potential in the previous project and worthy of further testing.

However, most experiments focused on the priority species and genotypes found previously to be widely adapted and suited to integration with cereal-based crop rotations in previous work. Clitoria (butterfly pea; *Clitoria ternatea cv.* Milgarra) is a perennial legume capable of persisting for several years, with relatively easy seed production and establishment, and is resilient and consistent performer to a range of applications. This species has emerged as the favoured option for wider application and hence increasingly became the focus of our research. Centro (*Centrosema pascuorum cv.* Cavalcade) and lablab (*Lablab purpureus cv.* Highworth) are both annual legumes that have demonstrated favourable production under some conditions (particularly in wetter situations such as after paddy rice crops) but challenges with seed production are likely to limit their widespread adoption.

Almost all experiments were conducted in collaboration with local farmers, schools or local extension/rural development organisations to maximise their visibility and allow greater awareness and understanding of the forage legumes in these groups. In several cases students, farmers or development staff assisted with experiments and got first-hand experience with growing these forage legumes.

Plate 2. Priority forage legumes found to be adapted and suitable for integration with maize-based crop systems in Eastern Indonesia; left - *Clitoria ternatea* (Clitoria, Clitoria), centre – *Centrosema pascuorum* (Centro), right – *Lablab purpureus* (lablab).

Table 1. Summary of experimental activities conducted in the project aligned to research focus areas and activities across Indonesia and Australia between May 2014 and June 2018.

Exp. #	Experimental activities	Location, Node	Year
1.	**Forage legume agronomy**		
1.1	Sowing timing; +/- weeding (*x 3*) – Lablab, Centro, Clitoria	Naibonat, Kupang; Soe, TTS, Mbay, Nagekeo	2015-16
1.2	Sowing method & rate (*x 3*) – Centro, Clitoria Species x sowing method after rice – Centro, Clitoria	Mbay, Nagekeo; Walagai, Ende Ronokolo, Ende	2015-17 2017
1.3	Cutting frequency (Clitoria)	Soe, TTS; Walagai, Ende	2016
1.4	Legume evaluation in new regions	Waingapu, Sumba; Millapinga, Sumba Ranokolo, Ende	2015-16 2015-16 2017
2.	**Crop-legume integration**		
2.1	Legume sp. *x* +/- cutting in maize rotation	Gatton, Queensland	2014-16
2.2	Legume sp. x +/- cutting in maize rotation	Naibonat, Kupang	2015-17
2.3	Legume duration x +/- cutting in rice rotation	Mbay, Nagekeo	2016-17
2.4	Legume-maize intercrops & relay – Clitoria	Soe, West Timor Waingapu, Sumba	2016 2017
3.	**Livestock production**		
3.1	Ongole cow supplementation	Melolo, Sumba Praipuluhamu, Sumba	2015 2016
3.2	Bali calf survival and growth	Bipolo & Oesao, Kupang	2017
3.3	Ongole bull growth	Milipinga, Sumba	2017
4.	**Reproduction and seed production**		
4.1	Environment and sowing time effects on flowering & seed production – multiple species	Walkamin, Qld; Naibonat, Kupang; Soe & Tobu, TTS; Ende, Flores	2014-15 2015-16
4.2	Pole and living maize trellises on flowering and seed production - Clitoria	As above Soe, West Timor	2015 2016
4.3	Maize-legume relay-intercrops on seed production	Waingapu, Sumba	2017

5.1 Forage legume agronomy and management

5.1.1 Legume sowing timing and weed control (Experiment 1.1)

Three experiments, one each on Clitoria, Lablab and Centro set out to compare the impact of different sowing times on subsequent legume biomass production in order to quantify the potential production trade-offs for sowing later in the wet or early in the dry season (e.g. after maize). This was also done in combination with and without weed control to see how much this reduced legume production and to see if later sowing could reduce weed competition.

Replicated plots (3 x 3 m) were sown to forage legumes at 3 timings to coincide with early wet season (mid-late December), late wet season (early-late February) and early dry season (early April). Two of these experiments met with very dry conditions after sowing which compromised results of later sowing times, illustrating the risk of later sowing times.

Legume establishment density was measured 6-8 weeks after sowing and legume biomass production measured 90 days after sowing and then a final cut taken at the end of July when growth had stopped. Biomass cuts were taken from the whole plot (3 x 3 m), fresh weight measured and approximately 500 g subsample taken to partition into legume and weed biomass and to determine dry matter content of the biomass.

5.1.2 Sowing method and rate (Experiment 1.2)

A series of four experiments aimed to compare the effects of different sowing techniques and rates on plant establishment and biomass production of priority legumes (Clitoria mainly, with Centro included in some studies) in order to see if less labour-intensive methods than dibbling might be used for forage legumes. Four replicate plots of 2 x 3 m were laid out in a randomised block design including treatments involving a selection of 4 sowing methods (outlined below) and some experiments included a factorial with 2 sowing rates/densities (25 *vs*. 50 seeds per m^2).

- Dibbling involved punching a small hole to 2-3 cm depth with a stick and 2 seeds are placed in each position, covered and pressed. Plant spacing were 20 cm apart in 20 or 40 cm wide rows.
- Furrowing involved using a stick to create a 2 cm deep trench, with the seed distributed evenly along the bottom of the furrow and covered again with soil. This may or may not have been further pressed to improve seed-soil contact.
- Broadcast involves spreading the soil evenly over the surface and hence requires minimal effort but also reduces soil seed contact.
- Broadcast and harrow involved raking the area after seed had been spread over the surface in the attempt to improve the seed-soil contact.

Legumes were typically established in late January or February during the wet season into no-tilled ground that had been prepared minimally with applications of herbicide. One of the experiments (Ranokolo 2017) was sown in May into a rice paddy after harvest.

Measurements of plant population established via each method and rate were taken after 6 weeks at 2 x 1 m^2 locations in each plot. Legume biomass production was measured at 100-120 days after sowing via 2 x 1 m^2 quadrats in each plot. Samples were weighed fresh, a subsample taken and dried to allow determination of total dry biomass per ha.

Labour inputs for sowing

A key issue identified in the research was the labour required to establish the forage legumes. To respond to this local Indonesian field research staff conducted repeated tests of the time taken to complete sowing over 2 x 12 m test areas using different establishment approaches and techniques. All staff had experience with each activity recently and aimed to replicate typical speed that would be used over an hour or more. We also included some sowing equipment being provided locally by FAO to compare these with traditional methods. Time taken for each establishment activity was recorded and this was then calculated on an m^2 per person-hour basis. Different row spacings were examined for the row planting techniques used, as this will influence the area of land that can be covered in a given time. At the end of all different techniques three staff were asked to assess the energy required during each activity on a scale from 1-10 (least to most). Costs of establishment were estimated based on local rates; Rp50 000 per day for manual farm labour, Rp1.5M/ha for tillage with a hand tractor.

Plate 3. Testing the labour inputs required for sowing and cutting forage legumes.

5.1.3 Legume cutting management (Experiment 1.3)

Two experiments aimed to investigate how cutting frequency affects biomass production and quality in Clitoria in order to provide information on how it should be managed to maximise forage quality and production. On five replicated plots of 2 x 2 m four cutting frequency treatments (4-weekly, 8-weekly, 12-weekly and uncut) were imposed until 40 weeks (280 days) after emergence. Cutting started 10-weeks after emergence from crops sown in January, so that the crops were cut 6, 3, 2 and 1 times, respectively throughout the growing season. Initial legume establishment counts were taken at 6 weeks after sowing. Fresh legume biomass was measured from the whole plot area (2 x 2 m) and a subsample of 300-500 g taken and weighed immediately. This subsample was then partitioned into leaf and stem and dried to determine dry matter content and the proportion of leaf and stem in the biomass. Phenological development, such as the presence of flowers or pods were also measured every two weeks throughout the growing period.

Labour inputs for cutting

As with legume establishment, the labour required for cutting is a key issue for wider use of forage legumes. We compared the time taken and efficiency of cutting between a traditional method using a long knife, with locally available alternatives such as hand operated hedge trimmers or a petrol-powered brush cutter. The time taken to cut forage legume from a given area (8-12 m^2) was recorded for three separate individuals. This was used to calculate the area of legume cut per hour. The fresh forage biomass removed was then calculated for each method to estimate both a harvest efficiency and biomass harvested per hour.

5.1.4 Legume evaluation in new regions (Experiment 1.4)

The previous project had conducted extensive evaluation of legume genotypes across a range of environments, soils and systems in West Timor and Flores. However, with the expanded geographical range in the new project to include Sumba and new parts of Ende, three additional experiments tested the production of a wider range of forage legumes in these new environs. On Sumba, two differing sites at Wangga on a deep black vertosol soil and at Milipinga which had a very shallow red alfisol soil (40-80 cm depth) indicative of the natural pasture areas used for free grazing in the region. At these sites, eight and eleven genotypes, respectively, were sown on 22/23 January 2016 and biomass production measured every 90 days (2 cuts at Wangga and a single cut at Milipinga). The third site at Ranokolo (vertisol soil, 300 m asl), in the drier part of Ende region (north) included only 6 of the best performing species from elsewhere was sown on 21 Feb 2017 and monitored until August 2017, with 2 biomass cuts take over this period. All experiments used 4 replicated plots (4 x 2 m) and biomass measures taken from two 0.7 x 0.7 m quadrats per plot. All sites were sown on 30 cm rows and received no fertiliser or irrigation. Weekly observations of the occurrence of flowers and pods were also taken at these sites.

5.2 Forage legume integration with crops

Three multi-season rotation experiments were conducted to quantify the potential nitrogen that legumes could provide to subsequent cereal grain crops when grown in rotation. The first experiment, a legume-maize rotation, was conducted at Gatton in Queensland. Conducting the experiment in Australia and under irrigation allowed us to collect more rigorous measurements of the system and maximise legume and subsequent maize crop growth potential compared to research done in Indonesia, which used locally representative management conditions. Subsequent experiments in West Timor (Maize-legume) and Flores (rice-legume) provided local validation and demonstration of these results.

5.2.1 Legume-Maize rotation, Gatton, Qld (Experiment 2.1)

The experiment involved a rotation of five legume species and a maize control in the first year (Phase 1 – 12 Sept 2013 to 8 Apr 2014), followed by a bioassay oat cover crop (Phase 2 – 28 May to 14 Aug 2014) to ensure even starting soil water for the subsequent bioassay maize crop (Phase 3 – 10 Oct 2014 to 6 Feb 2015), which was planted to evaluate the impact of legume treatments on crop production. The experiment was conducted on a Black Vertosol (Isbell 1996) at the CSIRO Research Station Lawes in south east Queensland, Australia (27˚32'24"S, 152˚20'20"E). The legumes and maize control and the bioassay maize crop were provided with supplementary irrigation to both maximise potential legume growth and the response in the subsequent bioassay maize crop, thus minimising the impact of water limitations on legume growth and N fixation and subsequent crop N demand.

The field experiment was an incomplete split-split plot design with four replicates. For the first phase, the main plots (24 × 6 m) were a maize control (*cv.* PAC 735) and five forage legumes: Clitoria *cv.* Milgara, Centro *cv.* Cavalcade, Lablab *cv.* Highworth, Burgundy bean (*Macroptilium bracteatum*) *cv.* Juanita/Cadarga mix, and soybean (*Glycine max*) *cv.* Hayman. Subplot (12 × 6 m) treatments for each of the legumes were either cutting and removing the forage biomass (cut) or leaving the forage biomass uncut (uncut). The maize control was not divided into subplots, with grain and stover removed from the entire main plot.

After the legumes and the maize control, a bioassay oat crop was then planted across the experiment to re-establish consistent soil water across all treatments (Phase 2). Following the oat cover crop, a bioassay maize crop was planted to assess relative N supplied from the previous legume (Phase 3). Each legume subplot (cut or uncut) was then split into four N fertiliser rate sub-subplot treatments (3 × 6 m); fertiliser was applied at 0, 50, 100 and 150 kg urea-N/ha. At the same time, the maize control main plots were divided into eight subplots with eight N fertiliser rates applied, which included four additional higher rates to those applied to legume sub-subplots to ensure maximum fertiliser response was achieved (250, 375, 500, 750 kg urea-N/ha). These increments of urea-N enabled N fertiliser equivalence values to be calculate at lower levels of N inputs (≤150 kg urea-N/ha) while ensuring maximum N-unlimited yields were achieved, providing scope to measure higher N inputs (>150 kg urea-N/ha). As maximum maize yields were achieved with <250 kg urea-N/ha these higher N rates are not presented.

Irrigation was applied as required based on estimates of crop requirements in lots of 15-20 mm, up to twice per week throughout the growing season for the legume phase and bioassay maize crop. During experimental phase 1 this amounted to 634 mm of rain and irrigation (Figure 3). However, not all treatments grew for the entire period, since soybean and lablab failed to regrow after their respective cut and removal (149 and 64 days before legume termination) and the maize control was harvested 64 days before legume termination. During phase 2, there was 102 mm of rainfall during the subsequent fallow and oat cover crop and no irrigation was provided. During phase 3, 560 mm of rain and irrigation was provided to the bioassay maize crop.

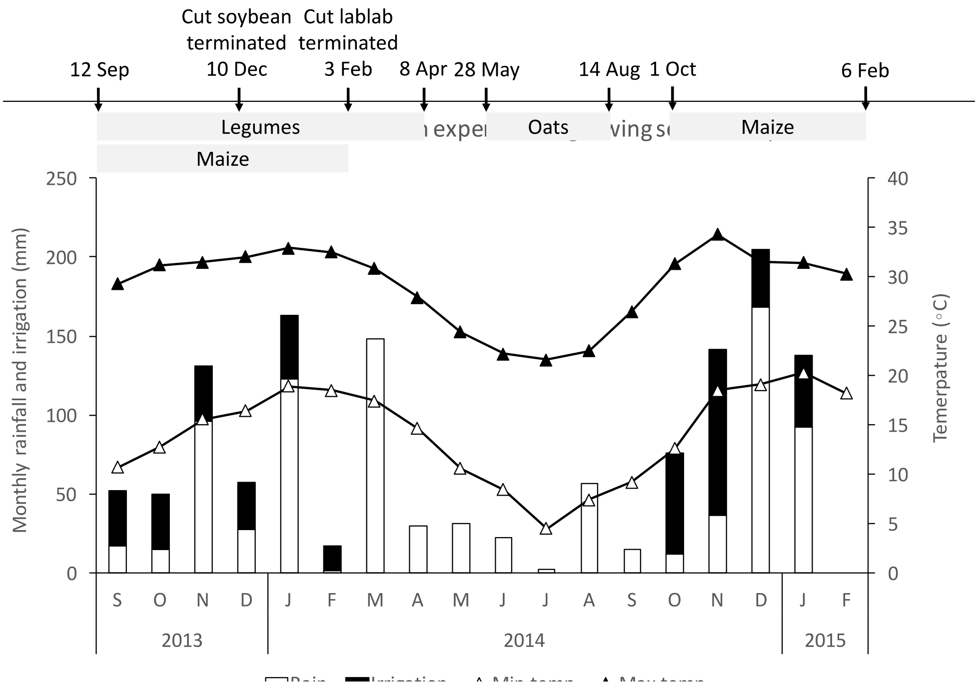


Figure 3. Monthly rainfall (white bars) and irrigation (black bars) and mean monthly maximum (solid triangles) and minimum (hollow triangles) temperatures and key activities during the experiment at Gatton (12 Sep 2013-6 Feb 2015)

Agronomic management: Phase 1 - Legumes and maize control

Legumes and the maize control were planted on 12 September 2013 with a no-till tyned cone seeder at recommended seeding rates and row spacing. A basal application of single superphosphate (8.8% P, 11% S and 19% Ca) was applied prior to sowing. During legume cultivation, weeds were controlled with a pre-sowing application of glyphosate (450 g a.i./L) at 2 L/ha and a post-sowing pre-emergent application of imazethapyr (700 g a.i./kg) at 140 g/ha in the legume plots and pendimethalin (440 g a.i./L) at 3.4 L/ha in the maize plots. Legumes were inoculated with commercial strains of rhizobium with peat slurry (Nodulaid®, BASF).

Once the legumes were approaching peak biomass (early flowering), shoot biomass in cut subplots was cut to a height of 70 mm above ground level and removed from the plots. Where legumes regrew, shoot biomass was removed multiple times following the process described above. Shoot biomass was cut and removed three times for clitoria and burgundy bean (76, 144 and 208 days after sowing (DAS)) and twice for centro (119 and 208 DAS) and lablab (82 and 144 DAS). At termination, all replicate plots were sprayed with glyphosate (450 g a.i./L) at 2 L/ha and dicamba (500 g a.i./L) at 400 mL/ha. Two weeks after spraying, uncut subplots were mulched with a tractor mounted flail mower set at 100 mm above ground level.

Each time legume biomass was cut and removed; biomass production was measured by collecting shoot biomass in three 0.25 m^2 quadrats (0.75 m^2) in each replicate legume plot. Maize grain and stover above the first node was harvested at maturity on 3 February from two adjacent 3 m lengths (4 m^2) of crop row in the centre of each plot. Maize grain and stover was also removed from the main plots to allow comparison to the legume subplots with biomass cut and removed and to also avoid confounding the N response curve used to calculate fertiliser equivalence values. Legume biomass samples and a sub-sample of 6 maize plants from each replicate plot were dried at 80°C until constant mass was reached. These samples were used to determine dry matter (DM), stover production and tissue N content.

Agronomic management: Bioassay oat and maize crops

After the legumes and maize control were terminated, an oat cover crop was sown in all replicate plots on 28 May 2014 to ensure even soil water at planting for the subsequent bioassay maize crop (Table 2). Biomass cuts were taken for the oats from each replicate legume subplot and maize main plots 78 DAS (14 August 2014) by collecting shoot material above 10 mm in two 0.5 m^2 quadrats and drying at 80°C until constant mass was reached. On the same day, the oat crop was terminated with glyphosate (450 g a.i./L) at 4L/ha. Following termination, oat biomass was mulched on 3 September using a tractor mounted flail mower set at 100 mm above ground level.

After the oat crop was terminated and mulched, a bioassay maize crop was sown on 1 October 2014 across the experimental area. Basal nutrients were applied to ensure nutrients other than N were non-limiting. Following sowing, atrazine (900 g a.i./kg) at 2.5 L/ha, S-metolachlor (960 g a.i./L) at 2 L/ha and glyphosate (450 g a.i./L) at 3 L/ha were sprayed across the experiment. Broadleaf weeds including volunteer forage legumes were controlled in-crop with 2,4-D amine (625 g a.i./L present as dimethyllamine salt) at 1.5 L/ha. Supplementary irrigation of up to 25 mm was applied each week from two weeks after planting until anthesis to ensure cumulative rainfall and irrigation >25 mm/week.

At maize anthesis, biomass cuts and tissue N content were measured from three adjacent 0.75 m lengths of crop row (1.5 m^2) in each replicate sub-subplot by collecting shoot material above the first node and drying at 80°C until constant mass was reached. Maturity biomass, grain yield and ear number were measured from two adjacent 3 m lengths of crop row (4 m^2) in the centre of each sub-subplot. A sub-sample of six plants was dried at 80°C until constant mass was reached and then threshed to determine biomass, grain yield and kernel weight.

Measurement of plant N accumulation

For all biomass samples, a ground subsample was analysed for total N (mg N g^{-1}) using a calibrated Bruker™ Near Infra-red Spectrometer. Total legume shoot biomass N for uncut subplots was measured using the N concentration for shoot material collected at maximum biomass (3 February), when total N was expected to be highest. This was calculated as:

Total shoot N retained = [(shoot DM at termination) x (shoot %N/100)]

As root N is not accounted for in shoot biomass N calculations, total plant N for uncut legumes was calculated by multiplying shoot biomass N by a root factor to estimate the additional below-ground plant N. As the impact of cutting on below ground N remains unclear (Unkovich *et al.* 2010), cut legume total plant N was calculated using below ground N from uncut legumes.

Total uncut plant N retained = [(Total shoot N retained) x (root factor)]

Total cut plant N retained = [(Total uncut plant N retained) – (Total uncut shoot N retained)] + [Total shoot cut N retained]

The root factors used were 1.8 for clitoria and burgundy bean based on the mean value determined across a range of perennial pasture legumes (45% below ground N; Peoples *et al.* (2012)), 1.49 for centro and lablab assuming partitioning of total plant N was similar to other annual legumes (33% below ground N; Unkovich *et al.* (2010)), 1.61 for soybeans (38% below ground N; Unkovich *et al.* (2010)), 1.85 for oats (46% below ground N) and 1.58 for maize, based on mean below ground N of a range of temperate cereals (37% below ground N; Wichern *et al.* (2008)).

Measurement of available soil N and water

Soil nitrate (NO_3-) concentrations and soil water content were measured four weeks prior to starting the experiment; there was 4 mm of rain between soil sampling and legume planting. Soil nitrate and water content were also measure in each replicate plot following the legume and oat crops and after the maize crop in plots with no N fertiliser applied. For each subplot or sub-subplot, soil samples were collected to a depth of 1.2 m for NO_3- and 1.5 m for water content. Samples were separated into 0-0.15, 0.15-0.30, 0.30-0.45, 0.45-0.60, 0.60-0.90, 0.90-1.20 and 1.20-1.50 m layers, with subsamples removed for NO_3- and gravimetric water content analysis. For gravimetric water content, each sample was weighed immediately, dried in the oven at 105°C for ≥ 3 days and then reweighed. Volumetric soil water content was calculated using bulk densities for a soil that had previously been characterised for the experimental site for the APSoil database, this was soil Lawes No037 (Dalgliesh *et al.* 2012). NO_3- was analysed at a commercial laboratory following drying at 40°C for ≥ 3 days using a 1:5 soil:water extraction (Rayment and Lyons 2011). Total soil N was calculated using bulk densities described above (APSoil, soil Lawes No037). Field soil N results are only presented for 0-0.45 m, as >92% of NO_3- was above 0.45 m. In-crop mineralisation was calculated using maize total plant N and soil N pre and post maize.

Statistical analysis

Analysis of variance in Genstat 16.1 (VSN International Ltd. Hemel Hempstead, UK) was used to determine statistical differences in soil N and water content, legume N concentration and maize production. Mean separation was tested using least significant difference (l.s.d) at $P<0.05$. Fertiliser equivalence values were determined using linear regression and analysis of variance. All data was normally distributed and not subject to transformation.

5.2.2 Crop-legume rotations in Indonesia

Legume-Maize rotation, Naibonat, West Timor (Experiment 2.2)

A legume-maize rotation experiment was conducted at a private field site (akin to a research station) in Naibonat in 2015 and 2016.

The site was prepared by growing a forage sorghum crop during the previous wet season and removing biomass to deplete and reduce site variation in soil nitrogen levels prior to the initiation of the experiment. The experiment was designed with four blocked replications with main plots 20 m x 4 m (80 m^2) sown to the four forage legumes, Clitoria *cv.* Milgarra, Centro *cv.* Cavalcade, Centro *cv.* Bundey, Lablab *cv.* Highworth, a grain soybean crop *cv.* Willis and a maize crop control *cv.* Lamaru on 24 February 2015. The maize seeds were sown in an arrangement of 0.8 × 0.2 m, the *Clitoria* and soybean were sown using a 0.3 × 0.2 m spacing (17 plants/m^2), Lablab using a 40 × 20 m spacing (12.5 plants/m^2), and centro using a 0.2 × 0.1 m spacing (50 plants/m^2). There was no fertiliser applied and all crops were maintained weed free through regular hand weeding. Due to dry conditions during the period after sowing, two irrigation applications of 67 and 52 mm were made on the 20 February and 7 March, respectively (Figure 4).

All legume plots (i.e. excluding maize) were divided into two sub-plots; one half the legumes were left uncut during the season and biomass was retained on the plot (UNCUT), while on the other half legumes were cut at start of podding and removed from the plot 1-3 times during the season (CUT). Legumes were terminated on 14 August 2015 by two applications of 2 L of Roundup™ (450 a.i./L), applied 2 weeks apart. The maize was harvested by hand and the residues removed. The plots were then maintained weed free during the subsequent fallow prior to sowing maize assay crops.

In the next two years after the legumes, maize cultivar Lamaru was grown to determine any benefits legumes provided to N provision for the subsequent crops. In the first year, maize was sown on 5 January 2016 and the second year on 10 December 2016. In both years maize was again sown with an arrangement of 0.8 × 0.2 m and grown under rainfed conditions. In the first year, all maize plots received an application of 46 kg of N/ha (100 kg of urea) one week after sowing. In the second crop, all plots following legumes were fertilised with 46 kg of N/ha (100 kg/ha urea) one week after sowing, however, the control plots (i.e. those following 2 previous years of maize) were split and treated with either 46 or 92 kg N/ha.

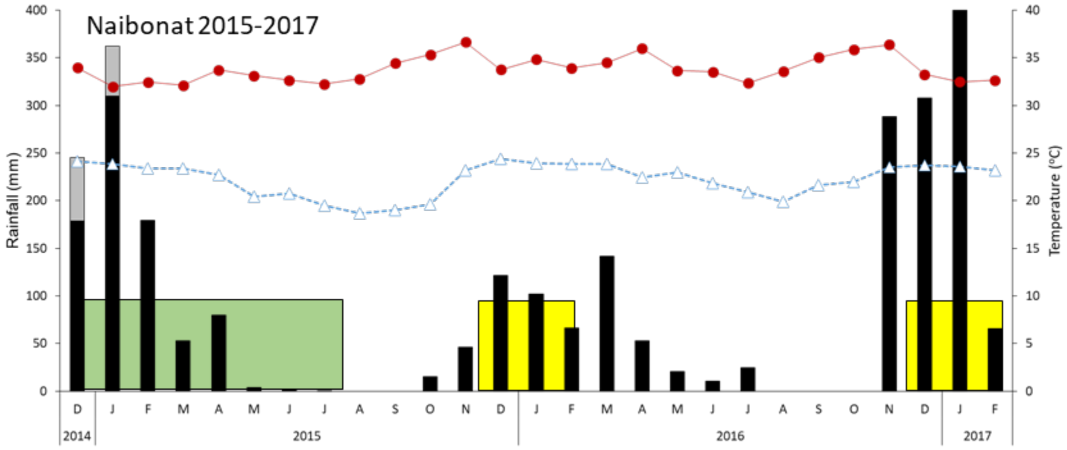


Figure 4. Climatic conditions during forage legume-maize rotation experiment at Naibonat between December 2014 and Feb 2017. Bars indicate monthly rainfall (grey indicates irrigation at sowing), and lines indicate maximum (red) and minimum (blue) temperatures. Periods marked as green were the legume crop growing period and yellow the subsequent maize assay crops.

Legume-Rice rotation, Mbay, Flores (Experiment 2.3)

The experiment was conducted in an irrigated rice paddy in a village where insufficient irrigation water limits dry season rice production across the whole paddy area. This allows for two niches where the forage legumes could be grown in rotation with rice. Legumes were grown either following the main wet-season rice crop allowing 6 months of dry season growth, or for a shorter period (3 months) following a second irrigated rice crop where the land would otherwise remain fallow (Figure 5).

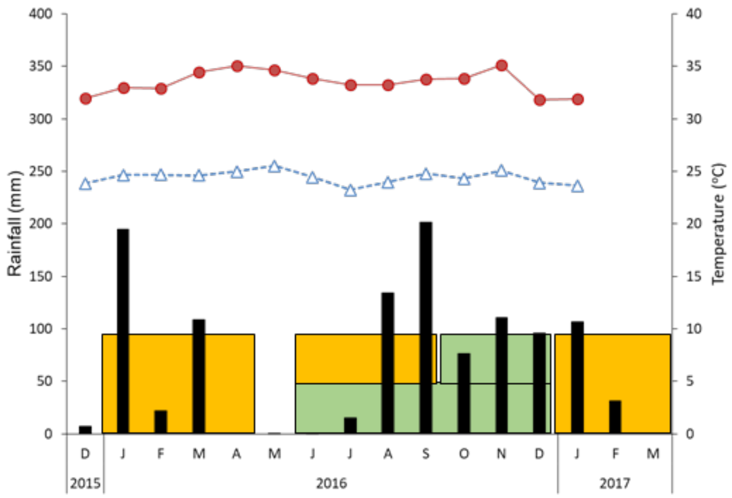


Figure 5. Climatic conditions during forage legume-rice rotation experiment at Mbay, Nagekeo between December 2015 and March 2017. Bars indicate monthy rainfall (excluding irrigation provided prior to sowing legumes), and lines indicate maximum (red) and minimum (blue) temperatures. Periods marked as green were the legume crop growing periods of differing duration and orange the proceeding and subsequent rice crops.

The experimental area was prepared by sowing the main wet season rice in January 2016, which received limited nitrogen fertiliser (100 kg N/ha at sowing) to reduce site variability. Following harvest of this crop, temporary bunds were erected to allow paddy rice and legumes to be grown in a block design with 4 replicates. Each block consisted of 5 main plots of 7 m × 5 m (35 m^2) which were allocated to 2 legumes (Clitoria or Centro), to rice (*cv.* Ciherang) that would be followed by each of these legumes, or rice that would be followed by a fallow. The early sown legumes were sown on 24 June 2016, following an initial irrigation. Rice seedlings were sown shortly afterwards (4 days) into a flooded paddy.

Following harvest of this rice crop, the shorter legume rotation was sown in 24 October 2016. The Clitoria and Centro seeds were sown in a 30 × 20 cm arrangement (17 plants/m^2). The Clitoria main plot was split, with half of the area left uncut over the entire growth period while legume growth was cut and removed after 3 months (later September) and allowed to regrow on the other half. Centro plots were left to grow over the entire period due to their poor ability to regrow after cutting. Only a single final cut occurred on the shorter rotation legumes. All legumes were terminated with a final cut and were removed from the plots on 5 January 2017, and the plots prepared for a subsequent rice crop, involving 2 tillage events. Care was taken during this process to minimise movement of soil between plot areas.

The subsequent wet-season rice crop was sown with seedlings on 16 February 2017 at 20 x 20 cm spacings. The rice-fallow control plots were split to allow for two fertiliser applications with the goal of predicting the fertiliser equivalents the legumes provided. Half of each rice control plot received higher fertiliser application of 92 kg of N/ha (as urea), while the other half of this plot received only 23 kg of N/ha as urea. The rice sown after the legumes also received this lower rate of fertiliser to allow comparison. All fertilisers were applied prior to the final tillage which incorporated them into the soil to avoid transfer between plots.

Forage legume production

Legume biomass was measured by cutting legume biomass at 2-4 cm above ground from two quadrats of 0.5-1 m^2 per replicate plot every 4-6 weeks over their growing season. Fresh weight was recorded and a subsample of approximately 200-300 g taken, weighed again and dried through a combination of air-drying on a concrete slab in full sun or an oven at 60°C for 2 days. Moisture content of the subsample was then used to calculate dry biomass per hectare. Accumulated legume biomass was estimated by the maximum growth achieved throughout the growing season.

Cereal grain crop productivity

The grain yield and biomass of all control and assay (after legumes) rice and maize crops were measured. Maize yield was determined by removing all cobs along 6-12 m of row (e.g. 2 rows × 3-6 m length) in each treatment plot (4.8 - 10 m^2). Cobs were counted and a subsample of 10 randomly selected, weighed, threshed and dried. The subsample was then used to calculate grain weight per hectare. Maize biomass excluding grain was measured at anthesis and/or at maturity. This was done by taking 6-10 plants (approximately 1 m^2) from a predetermined area in the central rows of plots (where subsequent yield samples were not to be taken). These were weighed and dried, and biomass calculated based on measured plant densities in each treatment (measured over 12 m of plant-row at anthesis). Rice grain was sampled from a 4 m^2 area at the centre of each plot, weighed, and a subsample taken to thresh and dry to determine grain yield. In the second phase of experiments, subsamples were taken to determine yield components such as kernel size for maize and rice, panicle/cob number, and grain mass per cob/panicle.

Available soil water and N

Soil cores were taken prior to sowing subsequent cereal assay crops to determine soil water and nitrogen status in some of the experiments. A 35 mm core was rammed by hand to a depth of 1.5 m in the centre of each plot, extracted and split into layers (0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm). A sample of each layer was taken, placed in a numbered tin, weighed and then dried for 24 h in a 105°C oven to determine gravimetric water content. A further sample was air dried on a concrete slab and tested for nitrate content using the RQeasy Nitrate test system (Merck KGaA, Darmstadt, Germany) for experiments 2 and 3 (2007-2009) or at an accredited laboratory at Bogor University using the KCl extraction method for experiment 4. Unfortunately, samples collected prior to the first maize assay crop were misanalysed for total N (Kjeldahl method) and further analysis of nitrate-N were not possible.

Statistical analysis

Analysis of variance using Genstat (VSN International) tested the effects of key experimental factors of legume/rotation crop, biomass retained/removed and N application effects on measures of cereal crop productivity in each study. Legume removal effects were examined without the inclusion of cereal controls in the analysis. Where statistical differences for experimental factors were found, least significant differences were provided to allow for comparisons. One-way ANOVA was used to determine differences in productivity of legumes sown on a common date in each experiment.

5.2.3 Legume – maize relay and intercropping (Experiment 2.4)

A series of three experiments were conducted where maize was grown in conjunction with the legumes in the interrow between maize crops with legume and maize sown together at the same time (intercrop), legumes sowing was delayed until the maize had reached flowering (relay) or the maize was sown into an existing stand of legume (oversown). In all these experiments the legume tested was Clitoria and a monoculture maize or forage legume crop was included for comparison. Some of these experiments were also used to assess both legume biomass but also seed production potential (sections 5.4.3 and 5.4.4).

Experiment 1 was conducted at Soe in 2016 involved 5 treatments: clitoria sown in either a monoculture on in the maize interrow at two times either two weeks after maize (28 January 2016) or at maize anthesis (11 March), and a maize crop control grown without clitoria to assess grain yield. ‘Dibble’ spacings of 40 x 20 cm were used for clitoria in all plots and maize integrated in rows at 100 x 40 cm in mixed-species treatments.

Experiment 2 was conducted at Wangga Sumba in 2017 involved seven treatments: clitoria sown at the same time as maize when maize was grown at 2 densities (2.5 and 5.0 plants/m^2); clitoria sown at maize anthesis (5 plants/m^2 only), clitoria sown alone (20 x 20 cm spacing) and maize crops sown alone at 2.5 and 5 plants/m^2. Replicated (4) complete blocks and 3 x 7 m plots were used. The experiment was sown on 14 February 2017 and no fertiliser or irrigation was applied as for local practice. The second planting of clitoria was conducted on 30 March (maize anthesis) and the maize harvested on 20 May. Clitoria biomass was measured in April and May.

Experiment 3 was conducted at Naibonat, West Timor tested sowing maize at different densities (3, 6 and 12 plants/m^2) into an existing stand of clitoria from the previous year. The legume crop was either removed entirely with repeated hand weeding or allowed to regrow after an initial cut at maize sowing.

In all these experiments, the maize cobs from the entire plot were removed, counted and a subsample of 10-15 cobs used to determine the average grain yield per cob which was then used to calculate the grain yield per ha. Legume biomass was measured at approximately 60 days after maize harvest using 2 m^2 quadrats and total biomass converted to a per ha basis allowing for the maize rows.

Plate 4. Forage legumes sown into interrow of maize crops(left) or into paddy after rice (right)

5.3 Livestock production impacts

A series of 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 under different production systems. In each experiment, legumes were provided to the farmers, but grown locally as part of engagement and demonstration activities.

5.3.1 Supplementation of Ongole cows during the dry season, Sumba (Experiment 3.1)

The effect of supplementing Ongole cows with herbaceous legumes during the dry season was assessed in two on-farm experiments in different locations and years in Sumba.

In 2015, 15 non-pregnant, non-lactating Ongole cows of similar LW and physiological status were selected from a larger herd in Melolo village (5 ± 2.0 years old (mean ± standard deviation), 221 ± 40.1 kg LW, BCS 2.3 ± 0.56 on 1-5 scale). Five cows were randomly allocated to the legume supplement group, while the other 10 cows were allocated 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. That received the legume supplement were penned as a separate group and were fed dried clitoria hay daily at approximately 10 g DM/kg LW, which was estimated to be adequate for maintenance of LW based on the energy requirements of Ongole cows (Antari *et al*. 2014b; Syahniar *et al*. 2012). Cows in the control group did not receive any feed overnight, which is standard practice for farms in this region.

In 2016, 30 non-pregnant, non-lactating Ongole heifers (2.3 ± 0.77 years old, 195 ± 35.4 kg LW, BCS 2.4 ± 0.49) were selected from a larger herd at Praipuluhamu village. Fifteen heifers were allocated to either a control group (no supplementation) or a group provided with clitoria hay overnight. Each group was managed as described for the first experiment, 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 three to five days, and compressed into that contained approximately 10 kg dry matter (DM) per bale. Farmers were asked to feed one bale of hay per five cows each night. No feed samples 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.

5.3.2 Supplementation of calves prior to weaning, West Timor (Experiment 3.2)

The impact of supplementation on calf mortality and LWG was investigated in two on-farm experiments. The first experiment (2016) conducted in conjunction with a Masters student from University Nusa Cendana failed to produce reliable data. Hence, a second study was conducted at Oesao and Bipolo villages in Kupang District of West Timor between September and December 2017 (16 weeks). Calves born between May and July and were randomly allocated to one of four treatment groups: control (no supplement, n = 16, (33 ± 9.9 kg LW)), legume hay (n = 13, 36.8 ± 2.1 kg), clitoria hay plus cassava (n = 14, 31.3 ± 2.7 kg), or a manufactured concentrate (n = 14, 33.5 ± 3.0 kg). Treatments were allocated evenly between 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 220 g DM/kg LW based on the recommendation of Jelantik *et al.* (2008b). 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. LW of calves 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 prior to flowering, and cured and conserved as described for experiment 3.1, with the exception that dried clitoria was chopped mechanically prior to baling. Sub samples of hay were collected from each bale and bulked prior to nutritional analysis (Table 2).

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

Table 2. Chemical composition of diets fed to unweaned Bali calves (experiment 3.2) and growing Ongole bulls (experiment 3.3).

	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

5.3.3 Supplementation of growing Ongole bulls (Experiment 3.3)

The growth rate of young Ongole bulls was assessed in a pen feeding trial at Milipinga research station in Sumba. Ten 18-month old Ongole bulls (157 ± 11.5 kg; all BCS 2) were housed in individual pens for 11 weeks between May and July 2017. Bulls were allocated 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 five 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. Bulls in the legume group were offered fresh clitoria at 20 g DM/kg LW (DM basis) 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 prior to feeding each morning then offered to bulls in approximately two 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 prior to the morning feeding. On two days each week, orts were separated into feed types and weighed to calculate average daily feed intake.

Bull LW, hip height and BCS of bulls were measured fortnightly in the morning prior to feeding. Sub samples of each feed type were collected monthly and air-dried prior to storage before nutritional analysis (Table 2). 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 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 (kg DMI per kg LWG) was calculated by dividing average DMI by average daily LWG.

Feed analysis

Dried samples were ground through a 2 mm screen. Organic matter was determined by combusting samples at 500-600 °C for 2 hours, total N was analysed using the Kjeldahl technique, and crude fibre was determined using the ceramic fibre filter method (AOAC 2012). Gross energy was measured using a Parr 6400 Calorimeter according to the operating instructions (Parr 2008).

Statistical analysis

Treatment effects on LW, BCS, hip height and feed were compared using t tests in Genstat (VSN International 2018). ANOVA was used to compare differences between multiple dietary treatments in the calf and Bali bull feeding experiments with Tukey's pairwise comparisons. Village was used as a covariate in the calf experiment. *P*-values were set at 0.05 significance.

5.4 Seed production research and development

A series of experiments were conducted at three nodes in ENT (Kupang, Soe, Ende) and in northern Australia to refine seed agronomy for the priority forage legumes (principally clitoria, centro and lablab). The aims of the research were to (1) better understand fundamental elements of seed crop management including site (region) selection and sowing time on seed crop development, and (2) test trellising methods which could be readily adopted by small-holder farmers to increase seed yields. A seed production network was concurrently developed to produce and supply seeds for testing and adoption, principally through regional government extension programs.

5.4.1 The influence of environment and sowing time on the onset of flowering (Experiment 4.1)

Photoperiodic responses of the onset of flowering are known to have a marked effect on the seed production of some tropical legumes and sowing dates are adjusted accordingly. The principal aim of this experiment was to identify the best time of the year to sow the key legumes in eastern Indonesia, which is at a latitude where the influence of photoperiod can be marginal. The Genotype by Environment (G x E) experiment was conducted over three years, initially in north-eastern Australia (north-eastern Queensland) using spaced plants to develop experimental principles for subsequent research in eastern Indonesia (small-plot studies) (Table 3). A minimum of 3 replications was used at all sites. Five legumes were studied at one site in Australia (~17°S) and four legumes at four sites in Indonesia (~10°S). The sites included a range of elevation (~40-900 m asl) and soil types (red and black clay soils of differing origin). The sowing date treatments spanned November to August at the Australian site and February to August (with one late sowing at one site during December) in Indonesia (Table 3). Fertiliser and irrigation were only applied at the Australian site and not at the Indonesian sites as for current practice.

Measures were standardised across the sites where possible using 0.7 x 0.7 m quadrats placed either around individual plants (Australia) or onto permanently marked positions within plots (two per plot). The measurements included: plant populations (4 weeks after sowing); number of nodes with expanded inflorescences (usually weekly); number of mature pods; and, at some sites the number and weight of seeds and following drying and threshing pods (only the flowering data are presented here). Each crop cycle was monitored for 6-8 months after sowing. Total daily rainfall and mean daily air temperature were recorded using data from on-site data loggers.

Table 3. Site characteristics and key treatments of the G x E experiment.

Indice	Walkamin	Kupang	Soe	Tobu	Ende
Region	Queensland	West Timor	West Timor	West Timor	Flores
Latitude (°S)	17.1	10.0	10.0	10.0	9.9
Elevation (m)	630	50	900	850	400
Soil type	Acidic red clay (ferrisol)	Alkaline black clay (vertisol)			
Legumes[1]	CP1, CP2, CT, LP, MB, VP	CP1, CT, LP, VL			
Sowing times	25 Nov. 13 7 April 14 29 Aug. 14	27 Mar. 15 27 May 15 27 Aug. 15	4 Feb. 15 9 Apr. 15 6 Jun. 15	11 Feb. 15 02 Apr. 15 08 Jun. 15	30 Mar. 15 15 May 15 30 June 15 15 Dec. 15
Design	Individual plants	Small plots: 3 x 1.2 m		Small plots: 2 x 1.2 m	
Replicates	30 plants/ species, 3 blocks	4		3	
Plant spacing	70 x 70 cm	40 cm rows x 10 cm within rows			
Trellis+/-	All legumes	CT	CT	CT	CT
Irrigation	dry season	none	none	none	none

[1] CP1 = *Centrosema pascuorum* 'Bundey'; CP2 = *C. pascuorum* 'Cavalcade'; CT = *Clitoria ternatea* 'Milgarra'; LP= *Lablab purpureus* 'Highworth'; MB = *Macroptilium bracteatum* 'Juanita'; VL = *Vigna luteola*' Dalrymple', VP = *Vignaparkeri* 'Shaw'.

5.4.2 The influence of pole or 'living' (maize) trellises on reproductive development (Experiment 4.2)

Previous observations under LPS/2006/003 indicated potential to increase seed yields per unit area of the key legumes using trellises. Two experiments were undertaken to test this:

First, the inclusion of simple 'pole' trellis treatments within the G x E experiments (described above), initially for five legumes in northern Queensland, and only for clitoria at the ENT sites as the method appeared best suited to this legume. At the conclusion of the November-sown growth cycle at the Australian site (6 June 2014), the individual plants of legumes which had previously shown a substantial flowering response to trellising were cut to 5 cm, all pods removed from the plants and counted and both components dried at 70°C until constant weight and subsequently re-weighed. The response for clitoria plants in ENT was simply expressed as a percentage change of the total number of flowers counted over the season with or without trellises.

A subsequent experiment made a comparison of flowering and pod and seed production of clitoria with and without the simple 'pole' or a 'living' maize trellises when legumes were sown as an inter-crop at Soe SMK (agricultural college), West Timor (vertisol 900 m asl). The design was a partial replicated (4) factorial including the following treatments: clitoria sown two weeks after maize (28 January 2016) or at maize anthesis (11 March); clitoria with no trellis, pole trellises or maize trellises at both sowing times. Maize was also grown without clitoria to assess grain yield (only clitoria performance reported here). 'Dibble' spacings of 40 x 20 cm were used for clitoria in all plots and maize integrated in rows at 100 x 40 cm in mixed-species treatments. No fertiliser was used, and the experiment only irrigated (by hand) if water stressed as a seedling. Flower and pod numbers were recorded in two 0.6 m^2 fixed areas within each 2 x 7 m plot. Pods were harvested weekly, dried and cleaned and yield recorded.

5.4.3 Integrating maize grain and clitoria seed production (Experiment 4.3)

An intercrop experiment was conducted on Sumba (vertisol, 50 m asl) in 2017 to test the capacity to fully integrate clitoria seed production and traditional maize grain production, with maize stalks used as a trellis for clitoria seed production after maize had been harvested. There were five treatments: clitoria alone (20 x 20 cm spacing); clitoria + maize (2.5 and 5 m^2) sown together; clitoria sown at maize (5 m^2) anthesis; maize alone (2.5 and 5 m^2). Replicated (4) complete blocks and 3 x 7 m plots were used. The experiment was sown on 14 February 2017 and no fertiliser or irrigation was applied as for local practice. The second planting of clitoria was conducted on 30 March (maize anthesis) and the maize harvested on 20 May. Clitoria flower numbers were recorded in permanent 2 x 0.9 m areas central to each plot. Clitoria pods were hand harvested within the same areas between 7 September and 3 November, counted, dried and threshed and seed weights recorded. Clitoria biomass was recorded during April and May, but these data are not presented here.

5.4.4 Statistical analysis

Simple statistics (means and standard errors) and Fischer's least significant difference procedure (P=0.05) were used to compare means of the variables.

5.4.5 Seed production and distribution

The development of seed production and distribution is required for regional evaluation and adoption of herbaceous legumes in ENT (and elsewhere in Indonesia). In village and within-project (BPTP staff and facilities) seed production was undertaken during LPS/2006/003, initially (and mostly) on west Timor near Kupang (lowland) and Soe (upland) and later on Flores between Ende and Mbay (upland and lowland sites). Seed production focussed on clitoria, centro and lablab, although other legumes were also grown by BPTP. The seed was mostly produced to support field research, demonstrations and government extension (Dinas) programs seeking to support the adoption of cattle production in ENT.

BPTP project staff were central to the coordination of seed production and distribution, which was at a relatively low level of production. Seed price was initially low (7000-10000 Rp/kg), being based in similar legume crops (mungbeans), but was increased to 30-40000 Rp/kg over this time based on a recognition of the labour costs involved in seed production (mostly harvesting). The further development of a seed production and distribution network was fostered over the current project, with seed production mostly near to Kupang and seed distributed to other regions of ENT and Indonesia.

Plate 5. Farmers in West Timor produced clitoria seeds for sale via BTPT NTT.

5.5 Socioeconomic impacts and participatory evaluation

Part of a doctoral dissertation by Traill (2017), this research assessed the potential role of forage legumes in mixed farming systems and how the socioeconomic impacts of forage legume adoption differ with farm type and gender. The study used bioeconomic modelling and participatory on-farm evaluation to identify potential socio-ecological niches for forage legumes and the potential impact on household resources such as income, land and labour.

5.5.1 Site selection

Six case study villages were selected to represent a range of elevations and soil types where mixed crop-livestock systems are common (Figure 6). At each village, one farmer group was selected, with a total of 6-10 households participating from each group (n=54 farming households).

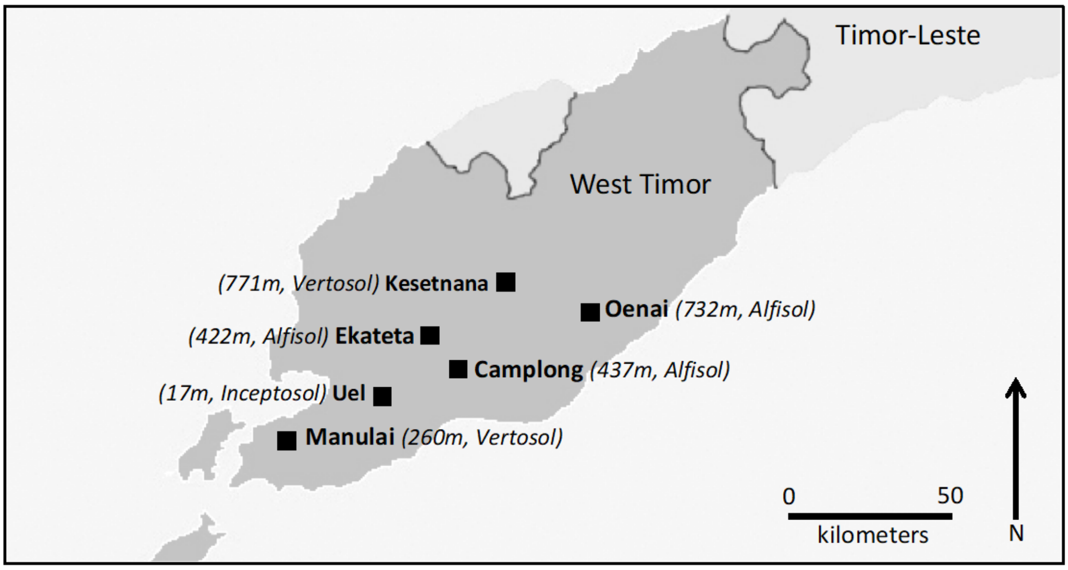


Figure 6. Map of West Timor and the 6 case study villages included in this study. Elevation (metres above sea level) and soil type are shown for each village.

5.5.2 Farm types

Key farm types across the case study sites were identified to understand how forage legume impacts differ with resources and cattle ownership (using whole farm modelling), as well as how farmers' legume production preferences differ with farm type (using participatory analysis). Farm types were identified using a short household questionnaire that captured key biophysical and socio-economic factors and crop and livestock practices for each household (n=54). Households were then grouped into clusters using principal component analysis (PCA) and subsequent cluster analysis (CA) (Table 4 and Figure 7). Of the 5 farm types identified, two farm types consisted of crop-focused households with low levels of cattle ownership (≤2), while the other 3 farm types were livestock-focused having ≥2 cattle.

Table 4. Characteristics of five farm types identified from a household survey (n=54) in 6 villages in West Timor and subsequent principal component and cluster analysis.

Farm type	House-holds (n)	Land (ha)		Cattle owned (total)		House-hold members		LLR (Land:labour ratio)[A]		Food security
Crop focused										
Crop focused low LLR	12	0.1	(0.1-0.8)	1	(0-2)	4	(2-8)	0.1	(0.1-0.4)	Sometimes
Crop focused high LLR	12	1.3	(0.9-2.0)	1	(0-2)	5	(4-10)	0.4	(0.2-0.6)	Always
Livestock focused										
Livestock focused dryland only	13	0.6	(0.1-1.0)	4	(3-7)	5	(3-7)	0.3	(0.1-0.4)	Nearly always
Livestock focused dryland and wetland	9	0.6	(0.3-2.0)	7	(2-18)	6	(3-11)	0.2	(0.1-0.5)	Always
Livestock focused wetland only	6	1.0	(0.2-1.5)	5	(2-10)	6	(3-8)	0.3	(0.1-0.7)	Some-times

[A]*Land:labour ratio; hectares of land per adults working on the area of land available*

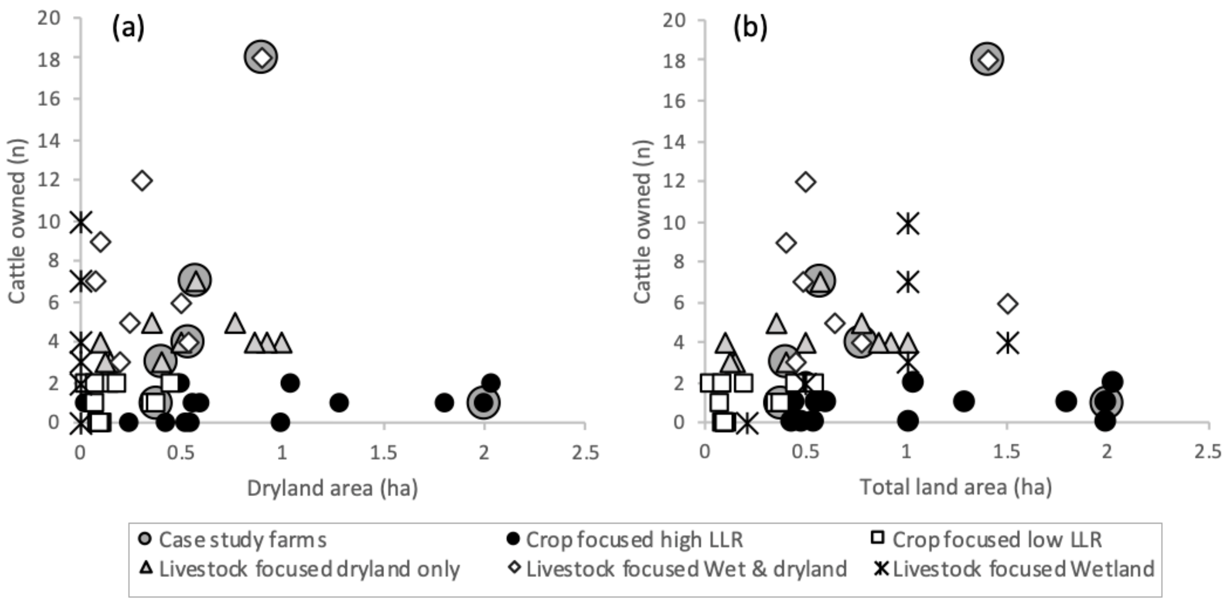


Figure 7. Classification of households (n=54) for a cluster analysis for 6 villages in West Timor. The five farm types identified are plotted against (a) their dryland area and cattle ownership and (b) total land area and cattle ownership. The case study farms (n=6) used for more comprehensive analysis are identified with a surrounding circle.

5.5.3 Whole farm modelling

Whole farm modelling was completed in two stages. Firstly, six case study households were selected from the 54 participating households to allow comprehensive analysis of the full range of legume management options as well as the impact of herd size and forage legume area. This case study analysis was used to identify the most beneficial forage legume management options, with the impact of these management options assessed for all 46 participating households with dryland farming areas.

Case study farms (n=6 farms)

Six households were selected to represent the diversity of farms identified in the household questionnaire (Figure 7). One case study farm was selected from each village, with the six farms selected also representing the range of cattle and land ownership identified. Whole farm modelling was limited to farms with dryland areas as participants indicated management options on wetland farms were largely limited to rotations.

The six case study farms were characterized using a second, more comprehensive, household questionnaire as well as a resource flow diagram. Each farm was then parameterised in the whole farm model the Integrated Analysis Tool (IAT), which simulates interactions between biophysical and economic processes for small-holder farms (McDonald *et al.* 2019, Figure 8). Critical to these simulations were differences in dryland area (where forage legumes were planted) and cattle ownership (produce income from forage legumes) for each case study farm (Table 5).

Table 5. Characterisation of key biophysical and socio-economic attributes for six case study farming households for baseline parameterisation of IAT.

Case study (Village)	Dryland owned (ha)	Dryland uncultivated (ha)	Maize (ha)	Forages (ha)	Total cattle (bulls)	Household members	LLR [A]	Household income (M Rp/yr)	Farm type
				Crop focused					
Uel	2.00	0.60	0.4	0.35	1 (0)	2	1.0	47.9	High LLR
Oenai	0.68	0.17	0.36	0.05	1 (0)	5	0.3	11.2	Low LLR
				Livestock focused					
Kesetnana	0.94	0.00	0.51	0.09	2 (1)	5	0.5	14.8	Dryland only
Manulai	1.99	1.50	0.05	0.05	4 (1)	6	3.1	27.1	Dry & wetland
Ekateta	1.93	1.42	0.45	0.06	6 (2)	3	1.0	22.1	Dryland only
Camplong	3.75	2.26	0.93	0.56	9 (3)	4	2.5	28.1	Dry & wetland

[A]*Land:labour ratio; hectares of land per adults working on the area of land available*

For each household, the IAT was used to analyse a matrix that compared the impact of a range of options for integrating forage legumes into small-holder farming systems. Three factors were included in the matrix:

1. *Forage legume management;* (a) maize forage legume relay, (b) maize-forage legume rotation, (c) forage legume permanent stand that replaces current maize crops and (d) forage legume permanent stand on unutilised land. All forages legumes were cut and used for cattle fodder. No nitrogen benefit to maize crops was assumed as the majority of legume biomass was removed for fodder.
2. *Forage legume area;* for the relay, rotation and permanent stand replacing maize the proportion of maize replaced increased incrementally from 10-100%. For the permanent stand on uncultivated land, legume area was increased incrementally up to a maximum of 1 ha (not all farms had 1 ha of uncultivated land)
3. *Doubling bull numbers*; the number of additional bulls was one for Uel, Oenai, Kesetnana and Manulai, two for Ekateta and 3 for Camplong.

A total of 42 different scenarios run for each farm from 2001 to 2010. The interactions between these three factors were assessed to determine their impact on fodder quality, livestock production, household income and food self-sufficiency.

To achieve this, crop, forage and native pasture inputs for IAT simulations were generated using farming systems model APSIM. Simulations used climate data from government and project meteorological stations and previously characterised soils from the APSoil database. Crop and forage production were simulated for each location from 2001 to 2010 using varieties, sowing date, configuration and nitrogen applications that represented on-farm practice. For forage legume production, clitoria was planted in February at 15 (rotation & permanent stand) or 20 (relay) plants/m^2 and then cut for fodder ever two months (April, June, August). Rotations and relays were terminated in August; a new permanent stand was established every 5 years, with dry matter production multiplied by 0.8 in years 4-5 to account for declining productivity.

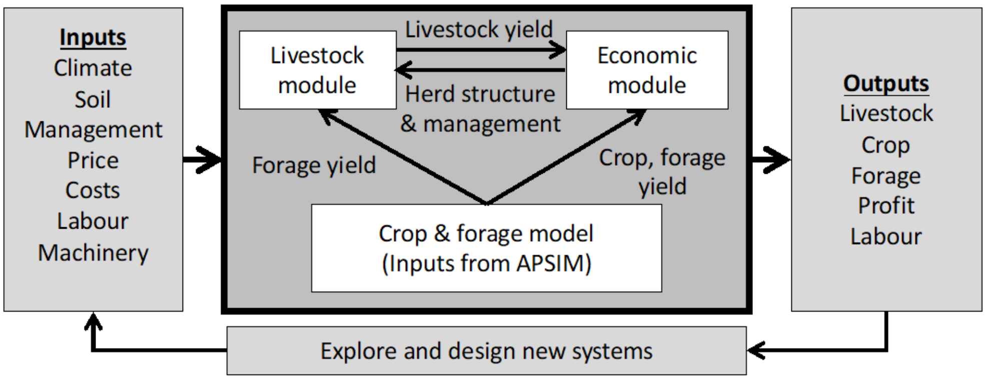


Figure 8. Schematic representation of the Integrated Analysis Tool (Lisson *et al*. 2010)

Farm type analysis (n=54 farms)

Case study analysis demonstrated that maize forage legume relays and permanent stands on uncultivated land provided the largest economic returns of the four management options assessed. The impact of these two management options was simulated for the 46 participating farming households with dryland areas using the same parameters described for the case study analysis. As was done for the case study farms, forage legume area was also varied for the relay (10-100% of the maize area) and the permanent stand (maximum 1 ha). For the permanent stand, only 8 farmers indicated they owned uncultivated land, however as there are a range of ways farmers can access uncultivated land (i.e. government land access, communal land, private rental) simulations included a permanent stand of up to 1 ha for each farm. Herd size did not vary.

5.5.4 On-farm participatory evaluation

To build on findings from the whole farm modelling, the 54 farming households involved in this research also grew forage legumes on their farm for two years (2014-2015). Participants selected between growing either clitoria or lablab. Farmers also determined the area planted on their farm (0.02 – 0.5 ha), legume management strategy (relay, rotation or permanent stand) and their production objectives – soil fertility, seed or fodder production.

Over the two years growing forage legumes, gender disaggregated focus group discussions at each village used participatory activities and farm types (described in section 5.1.2) to assess potential forage legume impacts and preferences. At the end of each year the benefits and constraints of forage legumes were evaluated using a modified ten seeds technique (Jayakaran 2002). Participants first identified key forage legume benefits, the number of factors identified (n=4-7) was multiplied by 5 and participants were given the corresponding number of counters. Participants then allocated counters to each benefit according to importance. This was then repeated for forage legume production constraints.

After two years, focus groups also assessed forage legume management preferences including variety (clitoria or lablab) and planting preferences (relay, sole crop or planted with other forages). To assess planting preferences, five different coloured markers representing five farm types (section 5.1.2) were distributed to the corresponding participants, who then placed the marker next to their preferred planting method. After this, each focus group discussed varietal selection and how labour and decision-making responsibilities for crop and livestock production were divided between men and women.

Given the constraints identified for forage legume production, forage legume clitoria was compared with grain legume cowpea (*Vigna unguiculata*) and tree legume leucaena, which are important legumes in West Timor. For each focus group, participants assessed whether focusing on increasing production of forage legumes, cowpea or leucaena was the most suitable option for each farm type (section 5.1.2) at their village. Participants first discussed the constraints faced by each farm type, and the advantages and disadvantages of each legume option. They then allocated a marker to the legume option which they considered most suitable for each farm type and explained the potential impact of that legume technology on labour, food security, costs, income and risk.

Plate 6. Farmers involved in participatory assessments looking at how forage legumes would fit into different farm types in each village. Photos courtesy of Skye Traill.

6 Achievements against activities and outputs/milestones

Objective 1: Develop forage legume use and management recommendations that optimise their growth, quality and impacts on subsequent crops

no.	activity	outputs/ milestones	completion date	comments
1.1	Research forage legume nitrogen fixation and impacts on subsequent crops (PC, A)	Develop/refine experiment operational plan	Nov 16	Four experiments were implemented where cereal crops were sown following legumes to assess the N benefits for subsequent crops in different systems (maize & rice) and environments (Gatton Oct 14 - Mar 16; Naibonat Jan 15 - Apr 17; Nagekeo Jan 16 - May 18; Ronokolo, Ende Jan 17 – Oct 17)
		Estimates of N fixation from forage legumes determined	Jun 17	Experiments at Gatton have shown that legumes can fix over 85% of their plant N or over 300 kg of N per ha. However, removal of legume biomass reduced the residual N fixed dramatically. These results have been published in a conference paper and journal article. Further results on N fixation rates are forthcoming with further analysis and publication of results from the Naibonat experiment.
		Impacts of legume and N application on subsequent cereal crop yields determined	Apr 16	Experiments demonstrated that legumes can contribute 50-150 kg N per ha to subsequent crops and can increase maize or rice yields by up to 100% when legume is retained, or 20-40% when it is removed. Yield benefits can last for up to 2 years.
1.2	Research on forage legume agronomic practise effects on growth and quality (PC)	Prioritise issues and develop/refine experimental plans at annual review and planning meeting (3/yr)	Oct 15 (annually)	Key agronomic aspects prioritised and experiments conducted over the project were - Evaluation of legume species in new environments (Sumba and East Ende, Flores) (3 experiments) - Establishment techniques and timing (6) and labour requirements for different methods (1 experiment) - Weed control impacts on legume production (3 experiments) - Cutting frequency and timing in Clitoria (2 experiments) and labour required for different methods (1 experiments) - Intercropping or relay of maize with legumes (3 experiments)
		Undertake experiments, collate data, report and review experimental outcomes	Oct 15 (ongoing)	Key results from these diverse experiments have been reported annually at project meetings, have been prepared into 2 conference paper articles, and have been used to refine recommendations for extension of best-practice management of forage legumes. Further scientific outputs from this work are anticipated in the future.

no.	activity	outputs/ milestones	completion date	comments
		Conduct and report simulation analysis and extrapolation of relevant agronomic practises	Apr 18	Data from experiments at Gatton and Naibonat have been used to further validate and improve the APSIM models of lablab, centro and clitoria (this has yet to be published). Simulation analysis has examined potential legume production from different systems for use in farms (e.g. permanent stands, relay or rotations), which has contributed to whole-farm analyses. Simulations analysis has also examined the impact of maize crop management (population and weed control) on expected yield responses after legumes.
1.3	Research pest and weed management options in forage legumes (PC)	Prioritise pest management issues and develop experimental plan	Oct 16	The impact of weed pressure during establishment and early production of legumes was investigated in 4 locations/species. The effect of weeding on maize production in crops following legumes was also assessed. An avoidance strategy for mitigating damage from yellow butterfly in early dry season has been developed and tested on-farm.
		Undertake experiments, collate data and report experimental outcomes		Poor weed control during legume establishment has been shown to reduce legume production by 30-80%. Recommendations have been developed in extension fact sheets.

PC = partner country, A = Australia

Objective 2: Determine target timing and livestock classes to feed forage legumes to maximise their benefits in livestock production systems.

no.	activity	outputs/ milestones	completion date	comments
2.1	Research livestock responses to feeding forage legumes (PC)	Prioritise issues and develop/refine experiment operational plan	Oct 16	Five experiments have been planned and implemented investigating gaps in our understanding of cattle responses to legumes in: - Ongole cows – to mitigate loss of liveweight and body condition score during dry season and potentially improve reproductive performance - Ongole bulls – in response to farmer needs to increase bull growth rates - Unweaned Bali Calves – legume hay fed as an alternative to expensive concentrates to reduce mortality and increase liveweight gain
		Grow forage legume material as required for feeding experiments (3/yr)	June 17	Legume forage was grown in collaboration with farmers and made into hay to support forage feeding experiments and provide demonstrations to collaborating farmers.
		Undertake in-village and controlled feeding experiments, collate data and report experimental outcomes	Dec 18	Ongole cow supplementation and Unweaned Bali Calf experiments were conducted across multiple sites and seasons. The benefits for legumes to improve nutrition of cow-calf systems in the late dry season were demonstrated and results communicated at international conferences, though extension fact sheets, and through in-village demonstrations.

PC = partner country, A = Australia

Objective 3: Quantify the impact on profitability and livelihoods and identify key drivers and limitations for integrating forage legumes across diverse farming systems in ENT.

no.	activity	outputs/ milestones	completion date	comments
3.1	Farm Identification and whole-farm bio-economic modelling (PC, A)	Preliminary modelling scenarios completed (A)	Dec 15	A set of baseline simulations were developed in the Integrated Assessment Tool (IAT) based on previous work in Indonesia. Climate data for locations in ENT were developed based on existing datasets coupled with analogous data in northern Australia. Production of forage legume in different systems (relay, rotation and permanent stands), maize, rice and other key crops were simulated using APSIM using data for 2 representative locations.
		Identify 5 diverse farming systems across regions and obtain information required to devise whole-farm simulations (PC)	Jun 17	Initial focus group discussions were undertaken with collaborating villages to develop a set of 5 representative models in of farming systems across the 5 regional research nodes.
		Conduct sensibility testing to refine whole-farm simulations of regional farming systems (PC, A)	Jun 17	Simulation results West Timor have been presented to 6 participating villages and further development options examined in collaboration with these groups. This process has not been completed with households in Sumba or Flores.
		Conduct scenario analysis and communicate outcomes to stakeholders (PC, A)	Apr 18	Whole-farm simulations examining combinations of legume integration (area of land allocated, method of use) in combination with livestock intensification options have been conducted for over 50 households from 6 villages on West Timor, 2 villages in Flores and Sumba. A subset of these have been analysed thoroughly (prepared for scientific publication by Traill *et al*) but further analysis is warranted. Key results from whole-farm modelling analyses and participatory assessments have been presented directly to villages involved in these activities, at the past 2 annual project meetings and at ACIAR symposiums.

PC = partner country, A = Australia

Objective 4: Understand key physiological and agronomic influences on legume seed production to identify target production environments and best-bet seed production practices in eastern Indonesia.

no.	activity	outputs/ milestones	completion date	comments
4.1	Research physiological and agronomic influences on forage legume seed production	Prioritise issues and develop/refine experiment operational plan	Oct 16	Seed production research took place over 2 stages. The first 2 years examined phenological and reproductive development and seed production of several tropical legumes across sowing dates and locations varying in latitude, and altitude to understand better conditions that favour seed production in tropical forage legumes The second set of experiments examined the opportunity to produce Clitoria seed in maize-clitoria intercrop systems.

no.	activity	outputs/ milestones	completion date	comments
		Confirm and prepare sites for Experiment 1 (flowering behaviour, two years) in Indonesia and Queensland	Jun 16	Experimental sites were established at 4 locations in ENT (Tobu, Soe, Naibonat, Wallafeo) and 1 location in Australia. These were chosen to represent upland and lowland environments across 2 islands in ENT and a higher latitude sites in Australia
		Undertake Experiment 1 , collate data and report experimental outcomes	Jun 16	Data on flowering and seed behaviour of diverse tropical legumes across locations identified daylength sensitivity in lablab and Vigna. This restricts their sowing for seed production to early dry season. Clitoria demonstrated daylength insensitivity and can be grown for seed across many sowing dates and environments. Trellising was also shown to be highly beneficial for Clitoria flower and seed production. These results were published in a conference paper at the AAAP.
		Confirm and prepare sites for Experiment 2 (plant architecture, two years) in Indonesia and Queensland	Jun 17	Four experiments examining Clitoria seed production responses to trellising either with wooden poles or co-sowing with maize were designed to investigate this over 2 seasons across 2 locations (Soe x 2, Sumba, Naibonat)
		Undertake Experiment 2 collate data and report experimental outcomes	Jun 18	Two experiments demonstrated potential to integrate Clitoria seed production in a maize intercrop. Maize provided some trellising benefits. Two further experiments were unsuccessful due to both implementation and environmental problems.
4.2	Seed production training and demonstration	Confirm international seed training participants (to deliver in-Indonesia training), program and venues	na	Project staff including junior scientists all received training and instruction in seed production methods and approaches. No other candidates for this training were identified and hence further formal training of Indonesian participants was not pursued further. However, the project team have delivered regular guidance and support to collaborating farmers & farmer groups. They have facilitated production of over 1 tonne of Clitoria seed over the life of the project.
		Training materials developed and translated into Bahasa where appropriate	Jun 19	Extension leaflets with recommendations on seed production suitable for distribution to farmers and farm advisors have been developed.
		Complete international training course in Australia and (if possible) Thailand	na	No candidates were identified for this training.
		Training materials refined for in-Indonesia training and translated into Bahasa	Dec 18	Simple how-to guidelines and farmer-friendly demonstrations were developed to be used by the Indonesian team in their training and on-farm demonstrations.

no.	activity	outputs/ milestones	completion date	comments
		In-Indonesia training courses delivered by Indonesian seed specialists	Jun 19	The project team has supported with advice and demonstration over 50 seed producers over the life of the project. Seed production was an integral component of training conducted in Objective 6 (below) and accompanying demonstrations, supporting materials were delivered by the project team.

PC = partner country, A = Australia

Objective 5: Improve knowledge and skills in legume-based crop and livestock systems and systems research approaches in Indonesian research and farming communities.

no.	activity	outputs/ milestones	completion date	comments
5.1	Mentoring & training of Indonesian research staff	Recruit 5 junior scientists (PC)	n/a	Five junior scientists were recruited in Aug 13, however 2 of these left the project between Dec 13 and May 14 due to delays in signing the head agreement.
		Language and research training of junior scientists in Australia (A)	Jan 16	The initial 5 junior scientists undertook English training and a 6-week intensive research training in Australia between Oct and Dec 13. The 2 replacement junior scientists were also provided opportunities to undergo formal English training after their appointment.
		On-going training in research and engagement methodologies provided to junior scientists (PC)	Jun 18	The Australian project team has delivered several key training activities over the project which have involved practical components that the project team have applied in their project activities. - Experimental design & protocol development - Data management using Microsoft Excel - Using Powerpoint for presentations - Undertaking participatory research and farmer consultations - Designing and monitoring effective on-farm demonstrations
		Local researchers present at annual science updates and research planning meeting (PC)	Oct 15	All Indonesian researchers involved in the project made annual presentations (10-20 mins) on their own results or on key research areas each year to both project staff and other stakeholders. Many of the team have also coordinated or presented information or demonstrations on forage legumes at local field days, to school or university students or at other organisation events (e.g. DINAS, FAO).
		Workshops held to assist local research staff develop scientific publications and presentations (PC)	Jul 18	Training on preparing for and delivering effective presentations was provided to local project staff in the lead up to and after annual project meetings. The project team has co-developed several conference papers during the project and a plan for a scientific paper writing workshop involving Indonesian and Australian scientists.

no.	activity	outputs/ milestones	completion date	comments
		Local researchers present project output at national and international conferences (PC)	Jun 18	Indonesian researchers have presented their research at several national and international conferences (e.g. Australia Agronomy Conference, AAAP, International Nitrogen Initiative Symposium, annual BPTP conference, ACIAR Symposia).
		Identify 2 post-graduate students and relevant projects (PC, A)	Oct 17	Skye Traill (nee Gabb) completed her PhD studies in collaboration with this project from 2013-2017. The project collaborated with 1 Masters student from Nusa Cendana University, but this link ceased after the student failed to fulfil their work program. One junior scientist employed on the project was supported to undertake a Masters at Nusa Cendana University, but for personal reasons had not completed at the finish of the project.
5.2	High school curriculum training and development	Five high schools and teachers are identified for curriculum training (PC)	Jun 16	We met with several SMK agricultural high schools at the start and throughout the project but found there was little opportunity to influence the curriculum significantly. However, we have continued to collaborate with 2 high schools in Soe and Nagekeo to support teaching staff and provide students practical training on growing and using legumes in farming systems.
		Australian volunteer curriculum development officer identified and engaged (A)	na	This was not pursued based on guidance from local schools.
		High school teachers undergo 2-3 week training visit to Australia (A)	na	This was not pursued based on guidance from local schools.
		Australian volunteer curriculum development officer visits Indonesia and changes are made to school curriculum. (PC)	na	This was not pursued based on guidance from local schools.
5.3	Supply-chain engagement & testing of forage legumes	Representatives of supply chain (e.g. traders, transport) present at project design and review meetings (PC)	Oct 15 (annually)	We have had several interactions with both the livestock traders association and the new abattoir in Kupang during the project. Key representatives of the trader association attended several annual project meetings and the final project review.
		Engage with supply chain reps to discuss opportunities for collaboration on the use of legumes in supply chain activities (PC)	Jun 18	Invitations to livestock traders association to attend project activities produced some on-farm demonstrations associated with these networks. Initial consultation with the new abbatoir in Kupang for planting and using legumes for improved cattle quality especially while waiting to slaughter – this venture has since discontinued.

no.	activity	outputs/ milestones	completion date	comments
		At least one example of other parts of supply chain testing the use of forage legumes (PC)	Jun 18	One influential member of the livestock trader association has purchased 5 kg of clitoria seed to establish for forage production area for feeding during holding time prior to and during transport. Members of the local beef cattle society have also been involved in project training and have become strong advocates for feed forage legumes.
5.4	Develop capacity in government and industry agencies	Staff from partner agencies present at annual project review & planning meetings, participate in exchange visits or workshops (PC).	Jun 18	Key DINAS leaders, other NGO's (FAO, PRISMA) have participated in annual project meetings and provided feedback on project activities and directions. Many DINAS staff have undertaken training related to using leucaena where the potential for complimentary benefits of herbaceous forage legumes has been introduced.
		At least 2 collaborative on-farm experimental activities demonstrating forage legume production and seed multiplication practices with producer groups annually (PC)	Jun 18	The project has maintained active engagement with over 10 villages each year (2 Sumba, 6-8 West Timor, 2-4 Flores). These sites have hosted on-farm agronomic and livestock feeding studies, been involved in participatory assessments of forage legumes and or produced seed or forage for project research activities. Where possible these engagements have been coupled with other complementary programs in these villages in either Leucaena projects, DINAS livestock development programs or FAO village activities.
		Train the trainer (extension staff) to transfer knowledge and information led by BPTP science and extension specialists	Jun 18	Each year project staff have delivered 4-5 training events to DINAS and farmer groups. This has often complimented training or development activities associated with extending leucaena. The project used these opportunities to demonstrate and introduce herbaceous forage legumes as a complimentary technology to Leucaena. This was further enhanced through an expansion of training in Objective 6 (below).
		Project update/summary held with policy and leading government agency staff (PC)	Jun 18	We have held several briefing meetings with heads of BAPPEDA & DINAS during the project. This has seen them start incorporating forage legumes into their livestock development programs across ENT. We also presented our research at the ISAINI International Symposium in Senggigi Lombok to several key agencies responsible for beef development in Indonesia (ICARD)

PC = partner country, A = Australia

Objective 6: Variation 2 Maximising potential impact of project outputs

no.	activity	outputs/ milestones	completion date	comments
6.1	Training program for Next Users	Prepare workshop content & supporting materials	Oct 18	The team worked together to arrange workshop content, materials including extension fact sheets, demonstrations and a plan to target key next users for the project's information in government and non-government organisations.

no.	activity	outputs/ milestones	completion date	comments
		Deliver at least 6 training workshops to DINAS, NGO staff, school teachers, CropCow staff	Sep 19	A first round of three 2-day workshops including a day of presentations followed a field visit and practical demonstrations on day 2 were conducted in Feb 19. This involved 70 participants where a DINAS extension agent supporting a village along with the leading farmer attended. A second round of follow-up workshops (Aug-Sep 19) reviewed activities, respond to issues or questions and inspected successful outcomes of participants.
		Support implementation of on-farm demonstrations in at least 12 villages across ENT &NTB	Sep 19	All workshop attendee pairings (35) were provided with forage legume seed to establish demonstrations in their village. Field days were held at several villages.
6.2	Facilitate institutional planning to support ongoing adoption	Policy brief prepared and provided to government	Apr 19	A policy brief (2 pages) was drafted, provided to ICARD, local DINAS and BPTP leadership.
		Plan for provision and upscaling of seed production developed	Apr 19	A document recommending seed production and development requirements in ENT was developed, a meeting was had with BPTP head with some dedicated resourced promised to support BPTP to continue to administer forage legume seed in the region.
		Plan for succession in human resources in agencies to support forage legume R, D & E	Apr 19	No clear plan for succession of skills in forage legume research and development were identified in the region.
6.3	Publish key research findings	2-week writing workshop held with key project researchers from Australia and Indonesia	Jul 19	Indonesian scientists (Nulik, Kana Hau and Hosang) travelled to Australia and spent 2 weeks working with Australian researchers (Bell, Cox and Mayberry) to collate and analyse data and develop paper drafts.
		At least 4 paper drafts prepared for submission in appropriate scientific publications	Dec 19	Three draft publications on Livestock production, Forage legume-crop rotations and Legume evaluation have been prepared and are ready for submission to scientific journals – outlines have been prepared for an additional 2-3 but these have not yet been completed.

7 Key results and discussion

7.1 Forage legume agronomy and management

7.1.1 Legume sowing timing and weed control (Experiment 1.1)

Experiments clearly showed the impacts that sowing date and weed control have on the relative productivity potential of forage legumes (Figure 9). These studies also show the impact that not removing weeds during establishment can have on reducing legume biomass. Clearly sowing in the early wet season provides the highest yield potential while later sowing dates corresponding with later in the wet season (e.g. at maize anthesis) or early dry season are exposed to higher risk of establishment failures and have lower yield potential, especially in dry seasons.

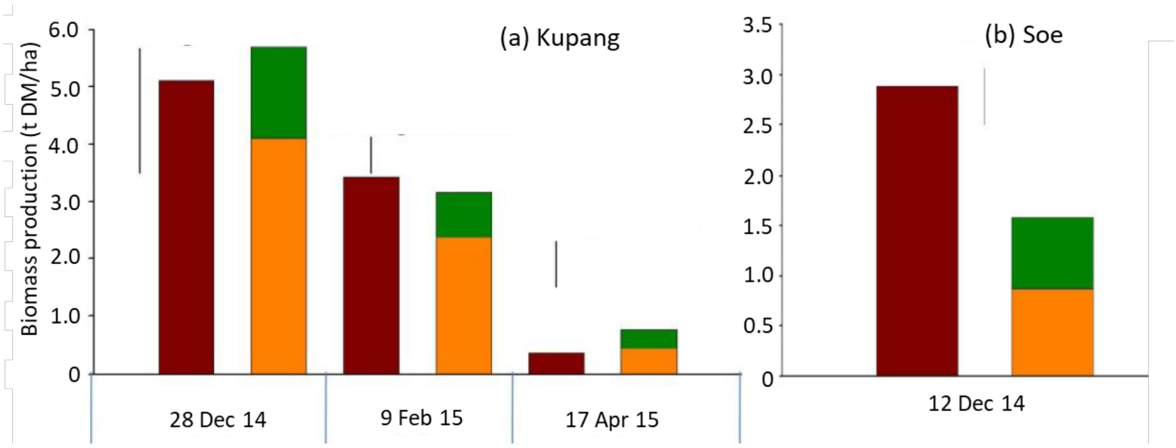


Figure 9. Biomass produced by forage legumes (t DM/ha) when sown on different dates representing early wet season (Dec), Mid wet season (Feb) and early dry season (Apr) when managed without weeds (red bars) or where weeds were allowed to grow (orange – legume, green – weed biomass) in two experiments at Kupang and Soe in 2014/15. Later sowing dates at Soe failed to establish due to dry conditions after sowing. Bars indicate lsd for each sowing date.

Collated across all experiments where legumes have been sown at different times and in different production systems, Table 6 shows the likely biomass production that can be achieved from the forage legumes when used in these various ways. This shows that while sowing legumes in relays or rotations after maize may allow them to be used on land otherwise unproductive of the dry season, this doesn't always produce very high legume yields.

Table 6. Summary of measured forage legume biomass production that is likely to be achieved when sown at different timings and in different systems in East Nusa Tenggara.

Production type	Establishment Timing	Legume biomass (t DM/ha)
Dryland	Early wet (Dec-early Jan)	3.5 - 6.0
	Mid wet (Feb-early Mar)	1.5 - 4.0
	Late wet (late Mar-Apr)	0 - 2.0
Wetland (paddy)	Post rice (Apr-May)	4.5 - 8.0
Supplementary irrigation		6.0 - 9.0

7.1.2 Sowing method and rate (Experiment 1.2)

A series of four experiments compared 4 main sowing methods for forage legumes to understand potential trade-offs between lower labour input options and the resultant plant establishment and biomass production that were achieved (see Figure 11). These experiments showed that in conditions with minimal land preparation (i.e. no tillage after only a herbicide application) the traditional method of dibbling often produced the highest plant populations and the highest subsequent biomass yield. Surface broadcast achieved the lowest establishment densities and subsequent biomass production and was particularly risky without follow-up rain. Following seed broadcast with harrowing or raking improved the outcome, presumably due to improving seed burial. There was some capacity to substitute higher seeding rates in these sowing methods to bolster plant establishment, but this was not reliable; in some experiments the lower seeding rates out yielded the higher seeding rates. On the other hand, when land was previously tilled there was an improved outcome in legume crops that were established using broadcasting and harrowing method such that it produced similar biomass yields and only slightly lower plant establishment. This data suggests there is capacity to use lower labour establishment techniques successfully for forage legumes and still produce satisfactory levels of biomass.

Collating these results across the various experiments demonstrated the legume production trade-off for sub-optimal establishment densities in Clitoria (Figure 10). This shows that to achieve the maximum biomass in each experiment, plant populations of 35-40 plants/m^2 were required and potential production would be halved if plant populations were halved. This provides compelling information on the plant populations of Clitoria that should be targeted in order to achieve maximum biomass production in their first growing season.

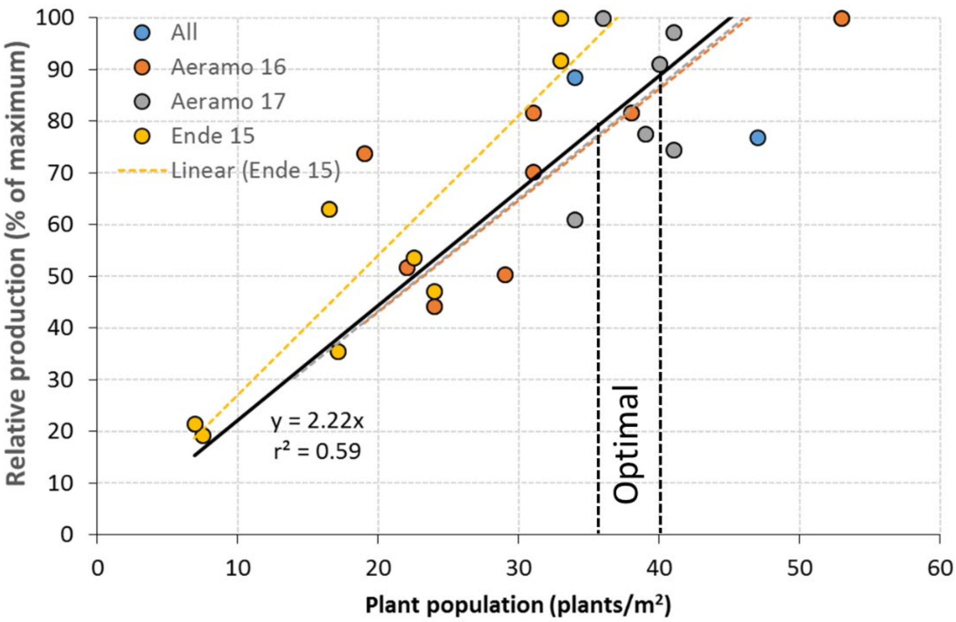


Figure 10. Relative biomass production (% of maximum achieved in an experiment) from Clitoria in the first growing season as related to established plant density collated across all experiments showing the potential production trade-off for reduced plant establishment.

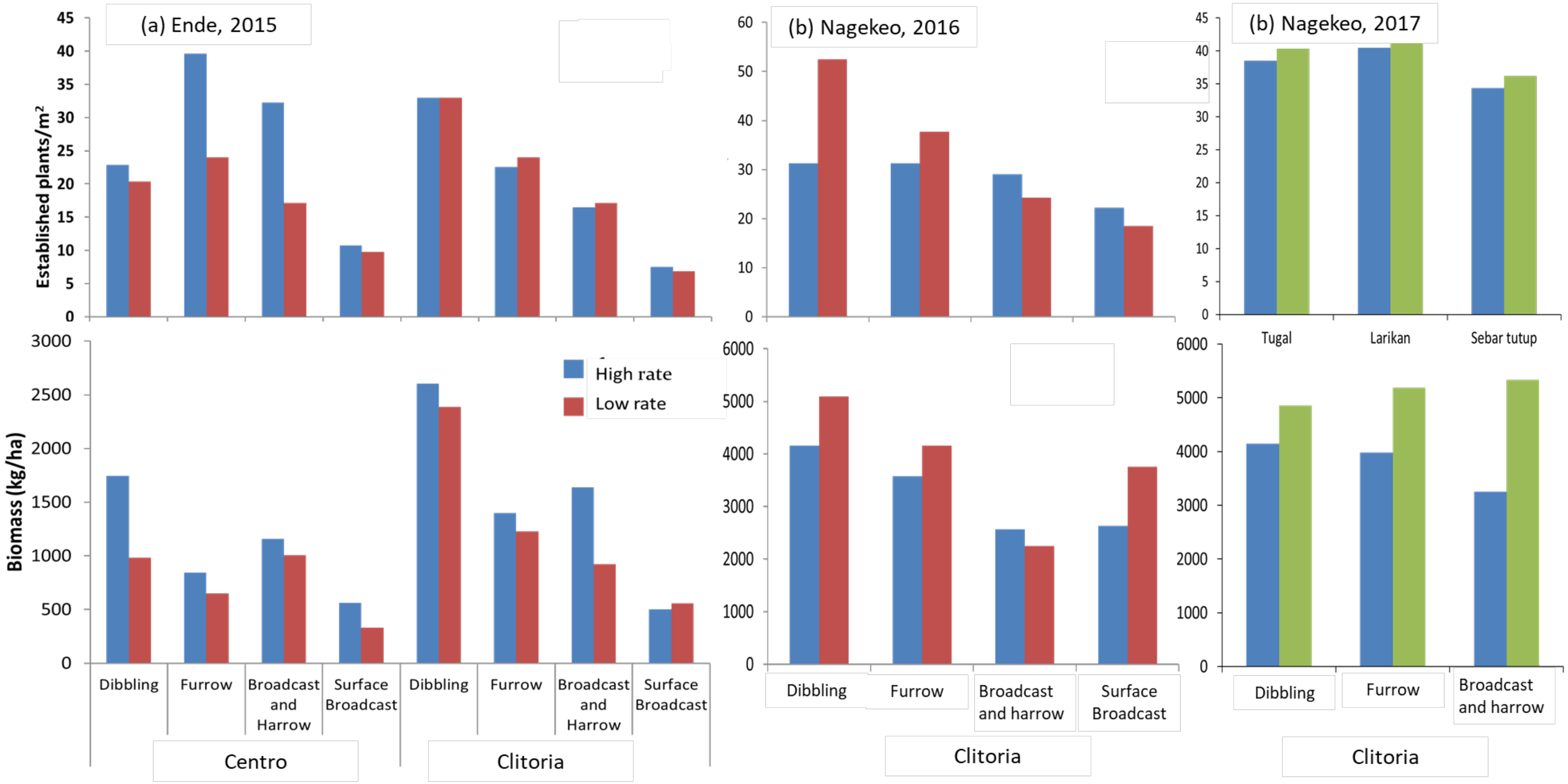


Figure 11. Established plant population (plants/m^2) and biomass produced (kg/ha) in the first 6 months after sowing when forage legumes were sown using different methods (Dibbling, Furrow, Broadcast followed by harrowing, and surface broadcast only) in combination with high (blue) or reduced (red) sowing rates (Ende 2015 and Nagekeo 2016), or with (green) and without (blue) previous tillage (Nagekeo 2017).

Labour inputs for sowing

Establishment of forage legumes was found to have a high labour requirement, but some alternative methods could reduce the time required. Our assessments found dibbling and furrow methods had the lowest sowing rates, which indicate that it would take 250 person.hours to sow 1 hectare of legumes at a row spacing of 30 cm. The highest sowing rate could be achieved from a broadcast only, but this method also has the highest risk of establishment failure and resulted biomass production of 30-50% of other methods. Following broadcast of seed with a harrow or raking treatment to work the seed into the soil was the next highest sowing rate and from our studies has only a minimal impact on subsequent productivity. This method would take < 50% of the time to sow than using the traditional method of dibbling but is probably restricted to periods when probability of rainfall after sowing is high. Some of the other new sowing equipment options tested also provided labour savings, with sowing rates 4-8 times higher than using dibbling. While their productivity impacts were not assessed we would expect similar productivity outcomes to dibbling.

Despite the time savings outlined above not all the methods outlined here are suitable for establishing seed into sites that have not been prepared with some tillage or similar. Tillage greatly enhances the establishment via broadcasting and harrowing and would also be required to make planting via a furrow or push-along wheel planter feasible. On the other hand, the several methods may be used with little or no soil preparation. Hence, the additional costs of tillage need to be considered. The estimated economic costs for the various sowing methods including the labour cost associated with the sowing activities, the cost of tillage and the cost of the new sowing equipment (assuming they are shared amongst a small group of farmers to sow 10 ha and last for 3 years). This clearly shows that the more labour-intensive systems would have a high cost for establishment of forage legumes and that once the need for tillage is taken into account the two mechanical systems that allow for no-till sowing have the lowest cost of establishment per ha. The estimated costs here are also quite high, indicating that systems where sowing of legumes needs only happen every few years (e.g. using Clitoria in semi-permanent areas or longer rotations with crops) would be highly advantageous over systems where sowing needs to be repeated annually.

Table 7. Forage legume sowing rate and effort required for different sowing methods, the relative productivity measured in experiments and a calculated cost per ha for sowing. Assumes a row spacing of 30 cm (equivalent to 12 plants/m^2) and tillage costed at 1.5M Rp/ha. Methods are ranked from most to least labour efficient.

Establishment technique	Requires previous tillage	Sowing rate (m^2/ person/hr)	Effort rating (1-low; 10-high)	Relative production	Cost per ha (M Rp)
Broadcasting	Yes	1633	1	30-50	3.2
Broadcasting + harrow/raking	Yes	477	3	60-80	3.7
FAO Wheel planter	Yes	386	1	na	4.0
Star (Poggo stick) seeder	No	158	5	na	3.1
Hoe fertiliser-planter	No	154	6	na	3.1
Dibbling	No	42	7	100	7.5
Furrow planting	Yes	38	5	80-110	11.0

7.1.3 Legume cutting management (Experiment 1.3)

Frequency of cutting was found to have a significant influence on cumulative biomass production and quality in Clitoria. Our experiments demonstrated that after allowing for a 10-week establishment period, cutting at high frequency of less than 6 weeks greatly reduced biomass accumulation by not allowing Clitoria sufficient time to recover after grazing and accumulate sufficient below ground resources to respond after defoliation. However, similar biomass production was achieved at other longer cutting intervals (8-16 weeks), although forage quality (here the % of leaf) tended to decline the later cutting occurred. Despite this, these results show a great amount of flexibility in cutting timing is possible to achieve maximal biomass production and without dramatic reduction in quality; here >50% leaf was still harvested when plants grew until mid-pod-fill (22 weeks after sowing). While this issue is important in Clitoria, it is less relevant in other forage legumes such as Centro and lablab that are suited to a singular cutting events, which is recommended at late flowering.

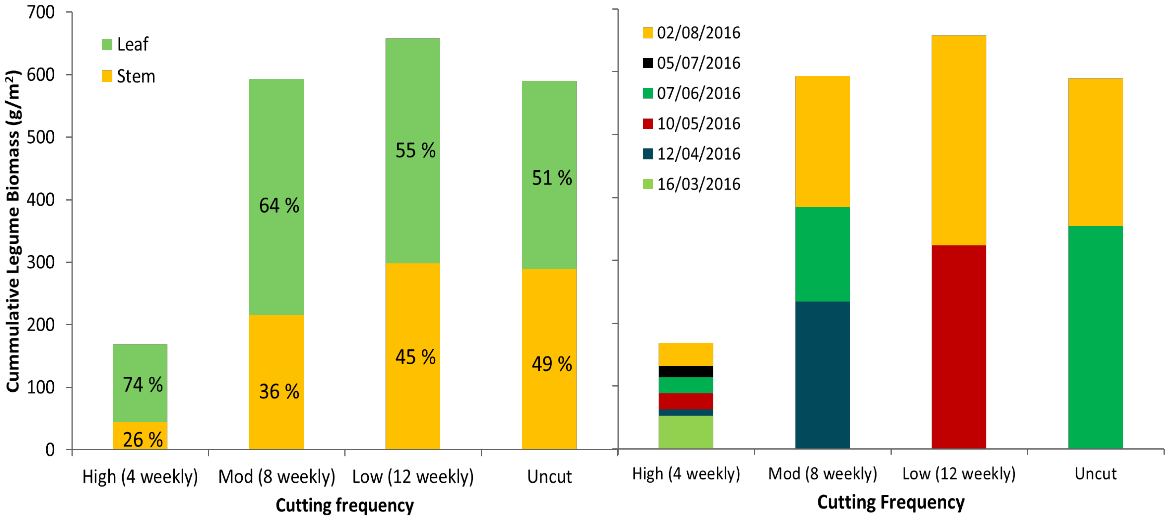


Figure 12. Cumulative biomass production (g/m^2) apportioned to leaf and stem (left) and biomass harvested at each cut (right) from Clitoria over a growing season at Walagai, Ende when subject to cutting frequencies at 4-, 8-, 12-weekly and cutting at mid pod-fill (uncut).

Assessments of labour requirements for harvesting legume biomass showed there was potential methods of increasing efficiency of labour. The use of a mechanical brush cutter was able to cut a larger area (e.g. 300 m^2/hr) compared to traditional methods (100-120 m^2/hr). However, this method had lower harvest efficiency (80%) with more legume biomass left in the field compared to using a hand knife or hedge trimmers. In the situation where this was assessed, with around 2.5-3.0 t DM/ha of forage legume we estimate it would take around 30 mins a day to cut sufficient forage to feed 3 bulls for fattening entirely on forage legume using the hand cutting methods, and < 20 mins using the brush cutter. Brush cutters although require a significant investment, if shared amongst a village may provide a viable option for cutting larger areas to make hay or conserve forage and allow cutting at times that optimise forage quality and biomass production potential. Options to reduce labour required for forage collection and mechanisation of this process was discussed with several collaborating farmer groups. However, the implications of this on labour allocations and socio-economics of this were not explored further.

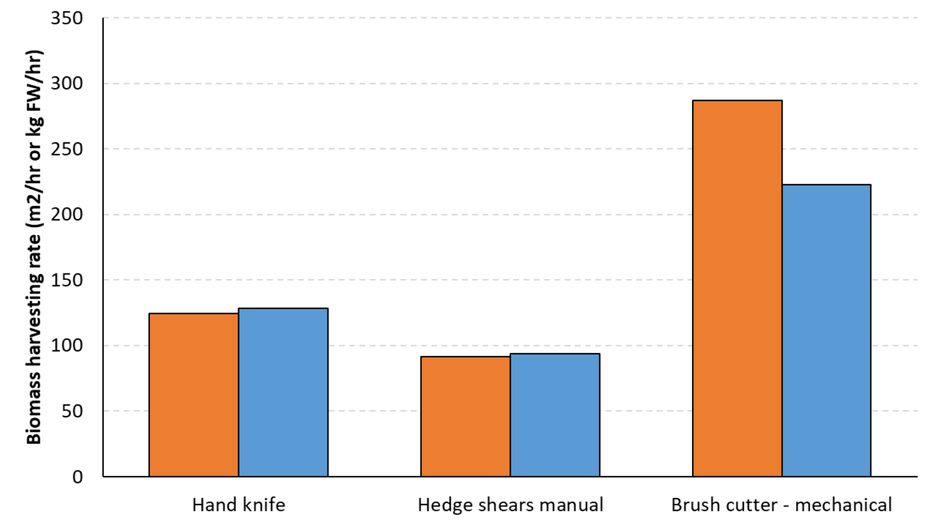


Figure 13. Labour efficiency for legume cutting using different methods in terms of area covered per hour (orange) or FW collected per hour (blue). The later will be affected by the amount of biomass available, but also by different harvest efficiencies of methods.

7.1.4 Legume evaluation in new regions (Experiment 1.4)

Herbage production of a range of legumes measured at the new sites (East Sumba and North Ende) were consistent with previous observations across ENT conducted in the previous project. Clitoria had the highest overall herbage yields (4.7 and 7.1 t biomass/ha) of all legumes on the two vertisol sites (Ranokolo and Wangga), due to a combination of rapid growth after establishment and regrowth after cutting. At these sites, the shrubby legumes Caatinga stylo cv. Unica (*Stylosanthes seabrana*) and desmanthus (*Desmanthus leptophyllus*) also regrew well after cutting, but overall biomass yields were lower than Clitoria. Of the other legumes, both Centro cultivars (Bundey and Cavalcade), Burgundy bean and Dalrymple vigna (*Vigna luteola*) initially yielded well, but regrew poorly after cutting, while Highworth lablab did not regrow at all (one site). These data further demonstrate the robust and reliable performance of Clitoria on heavy clay vertosol soils across multiple locations, while other species can perform well under certain conditions this is rarely at a level that outperforms Clitoria.

However, on the shallow upland alfisol site on Sumba, quite different results were observed. Generally, legume production was very low (< 1 t DM/ha at 96 days after sowing) and insufficient regrowth occurred to warrant meaningful assessments later in the dry season. The best performing legumes under this growing environment were the shrub legumes (caatinga stylo and desmanthus) and were the only legumes to persist through the dry season (observation only). Cavalcade centro was also included in the higher yielding group. This site demonstrates the limitations of Clitoria for use on the shallow soils which are typically left as native pasture. There may be some opportunities to use persistent legumes like caatinga stylo or desmanthus in these environs, but this would require further work and coordinated establishment and management works across all users of these common grasslands in order for successful augmentation with legumes.

Table 8. Biomass produced (kg air-dried material/ha) initially following sowing (days after sowing)and regrowth after cutting (days) and strength of flowering[1] by different herbaceous legume genotypes in three sites, Milipinga (Alfisol soil, 240m asl), Wangga (vertisol soil, 85 m asl), Sumba and Ranokolo (vertisol soil, 300 m asl) in north Ende during 2016 and 2017.

Site		Milipinga (sown 23 Jan.)		Wangga (sown 22 Jan.)			Ranokolo (sown 21 Feb.)		
Species	**Cultivar**	Initial (98)	Flwr	Initial (96)	Regrow (98 d)	Flwr	Initial (84)	Regrow (84)	Flwr
Centrosema pascuorum	Bundey						2180	320	*
Centrosema pascuorum	Cavalcade	350	***	2660	590	***	1040	0	***
Clitoria ternatea	Milgarra	190	***	3320	3790	***	2310	2350	***
Desmanthus leptophyllus	TQ90	90	*	1280	1190	***			
Desmanthus virgatus	Marc	40	*	1300	720	***			
Desmanthus virgatus	ES203	10	*						
Desmanthus virgatus	Q9153	410	***				210	1730	***
Desmanthus virgatus	Progardes	400	*						
Lablab purpureus	Highworth	100	*	1480	0	^{0}			
Macroptilium bracteatum	Juanita			2860	720	***			
Stylosanthes seabrana	Primar	690	***				140	490	***
Stylosanthes seabrana	Unica	760	***	2310	2250	***			
Vigna luteola	Dalrymple	220	*	1920	640	*	3240	1170	^{0}
p-value		<0.01		0.05	<0.01		<0.01	<0.01	
LSD (*P*=0.05)				1430	570		405	635	

[1] Flowering ratings: *** - strong, ** - moderate, * - weak, ^{0} – none)

7.2 Forage legume integration with crops

7.2.1 Legume-Maize rotation, Gatton, Queensland (Experiment 2.1)

Under the full irrigation all legume treatments produced >12 t DM/ha over 165 day growing period. The maize control crop yielded 4.36 t/ha and 12.2 t/ha of stover was removed. At legume termination residual shoot N was higher after uncut legumes (313 kg N/ha) than cut legumes (38 kg N/ha) (*P*<0.001). When shoot biomass was retained, clitoria total plant N was at least 150 kg N/ha higher than other uncut forages, however, when biomass was removed, total plant N retained for clitoria did not differ significantly from cut centro or burgundy bean (Table 9). Differences in total plant N retained were largely driven by the difference in root factors used for perennial (1.8; 45% below ground N) and annual forage legumes (1.49; 33% below ground N).

At sowing of the subsequent maize crop, soil N for the uncut legumes (59 kg N/ha) was higher than for the cut legumes (19 kg N/ha) and the maize (20 kg N/ha) (*P*<0.001, Table 10). During the maize crop, additional N mineralized following uncut clitoria (169 kg N/ha), centro (129 kg N/ha) and soybean (91 kg N/ha) compared to the maize control (*P*<0.001) (10). Cut clitoria and centro also increased N mineralisation, with an additional 70 kg N/ha mineralized for cut clitoria (*P*<0.001) and 47 kg N/ha for cut centro (*P*=0.15). At maize harvest an additional 15-26 kg N/ha remained following uncut clitoria and centro (data not shown).

Table 9. Measured shoot N and estimated total plant N retained following maize or forage legumes where shoot biomass was either retained or removed. Different letters indicate statistically significant (P<0.05) differences between species and shoot biomass management

Rotation Crop	Shoot N retained (kg N/ha)		Total plant N retained (kg N/ha)[A]	
Treatment	Retained	Removed	Retained	Removed
Clitoria	346 ab	50 c	623 a	329 cde
Centro	315 b	40 c	469 bc	193 efg
Lablab	264 b	36 c	393 cd	155 fg
Burgundy bean	259 b	37 c	466 bc	240 def
Soybean	374 a	33 c	601 ab	260 def
Maize	5 c		106 g	

[A]Adjusted to include below ground plant N using root factors, below ground N for cut legumes was assumed to be the same as uncut legumes

Maize shoot N concentration at anthesis following uncut legumes was 0.2 % higher than after cut legumes (P<0.001). This equated to maize accumulating an additional 60 kg N/ha of shoot N and 95 kg N/ha of total plant N when legume shoot biomass was retained rather than cut and removed (Table 10). Maize N uptake after uncut legumes varied between species; an additional 197 kg N/ha total plant N was accumulated after clitoria, 136 kg N/ha for soybean, 128 kg N/ha for centro, 94 kg N/ha for lablab, while burgundy bean failed to increase N uptake above control levels (P<0.001). When legume shoot biomass was cut and removed, no legumes significantly increased maize N uptake above control levels, although N uptake after cut centro and cut clitoria was higher than other legumes. In all cases only a small % of the estimated legume N was recovered in the following maize crop (Table 10), suggesting that further N benefits would accrue in subsequent growing seasons.

Uncut clitoria, centro and soybean increased maize anthesis biomass by 2.3-4.1 t/ha compared to the maize control, while uncut lablab and burgundy bean failed to increase biomass above control levels (P<0.01). No cut legumes increased anthesis biomass above control levels (Table 11).

Maize grain yield was highest following uncut clitoria (10.9 t/ha), lablab (9.2 t/ha), centro (8.8 t/ha), and soybean (8.2 t/ha) (P<0.01, Table 11). For these species, retaining instead of cutting and removing biomass increased maize crop grain yield from 2.4-4.9 t/ha to 8.2-10.9 t/ha and harvest index from 0.29-0.39 to 0.47-0.50 (P<0.001). In comparison, uncut burgundy bean failed to increase maize yield above control levels. Cut legumes did not increase grain yield above control levels, however the dry matter production and harvest index of the cut and uncut centro and cut clitoria were similar.

Differences in grain yield were mainly driven by kernel weight per ear, which doubled when legume biomass was retained rather than cut and removed (P<0.001). Consequently, for centro, clitoria, lablab and soybean, kernel weight per ear accounted for ≥80% of the difference in grain yields between cut and uncut treatments. The number of ears per hectare was 17% higher for uncut legumes (69,444 ears/ha) compared to cut legumes (59,259 ears/ha) (P<0.01) (data not shown). This equated to <1 ear per plant for cut legumes and >1 ear per plant for uncut legumes.

Table 10. Soil NO_3 (0-0.45 m) at planting of the subsequent maize crop, in-crop mineralisation, accumulated shoot N uptake for the maize bioassay crop and calculations of additional legume N accumulated and legume N recovered following either a maize control or forage legumes where shoot biomass was either retained or removed. Different letters indicate statistically significant (*P*<0.05) differences between species biomass management.

Rotation Crop	Soil N @ maize planting (kg N/ha)		In-crop mineralisation (kg N/ha)		Accumulated shoot N uptake (kg N/ha)		Additional N accumulated (kg N/ha)		Legume N recovered (%)	
Treatment	Retained	Removed	Retained	Removed	Retained	Removed	Retained	Removed	Retained	Removed
Clitoria	73 a	22 cde	289 a	190 bcd	207 a	123 bcd	197	65	32	20
Centro	33 bc	24 cd	249 ab	167 cde	162 ab	112 cde	128	48	26	25
Lablab	40 b	13 e	197 bce	103 f	141 bc	67 e	94	0	23	0
Burgundy bean	31 bc	19 de	140 cdef	129 def	101 cde	89 de	31	11	13	5
Soybean	67 a	18 de	211 bc	126 def	168 ab	86 de	136	7	23	3
Maize	20 de		120 ef		82 de		-		-	

Table 11. Maize grain yield, stover, kernel weight per ear, harvest index and anthesis biomass for an unfertilised maize bioassay crop following either a maize control or forage legumes where shoot biomass was retained or removed. Different letters indicate statistically significant (*P*<0.05) differences between species and shoot biomass management; n.s., not significant (P>0.05)

Rotation Crop	Grain yield (t/ha)		Stover (t DM/ha)		Kernel weight/ear (g)		Harvest index		Anthesis DM (t DM/ha)	
Treatment	Retained	Removed	Retained	Removed	Retained	Removed	Retained	Removed	Retained	Removed
Clitoria	10.9 a	3.5 c	10.9 a	6.4 cd	147 a	65 b	0.50 a	0.32 c	9.1 a	6.4 bcde
Centro	8.8 ab	4.9 c	9.9 ab	7.5 bcd	149 a	82 b	0.47 ab	0.39 bc	7.8 abc	6.5 bcde
Lablab	9.2 ab	3.3 c	9.1 abc	5.7 d	133 a	61 b	0.50 a	0.33 c	7.3 abcd	4.2 e
Burgundy bean	4.5 c	3.4 c	6.3 cd	6.6 cd	70 b	54 b	0.39 bc	0.32 c	5.9 cd	5.2 de
Soybean	8.2 b	2.4 c	9.4 ab	5.7 d	130 a	49 b	0.47 ab	0.29 c	8.8 ab	4.6 e
Maize	3.0 c		5.8 d		55 b		0.33 c		5.0 de	

Using the maize yield responses seen to the additions of urea fertiliser, we calculated the N fertiliser equivalence value for each of the legumes (Table 12). Maize yield following uncut clitoria, centro, lablab and soybean was equivalent to following maize when it was provided with 100-150 kg urea-N/ha. In contrast, uncut burgundy bean failed to contribute large amounts of N. Centro was the only legume when shoot biomass was cut and removed where contributions of N to maize yield and kernel weight per ear were detected. For the other legumes when shoot biomass was removed, maize yield and kernel weight per ear were equivalent to the control for all N fertiliser rates. Consequently, with the exception of centro, 100 kg urea-N/ha was required to alleviate the yield penalty imposed by removing N within the cut legume biomass.

Table 12. Estimated N fertiliser equivalents (kg urea-N/ha) required to achieve similar grain yield for a maize crop following forage legumes where shoot biomass was either retained or removed (Mean with standard error in brackets). Calculation based on response rate of maize grain yield to additional urea N applied (i.e. maize yield (t/ha) = 0.05 x kg N/ha + 3.27, r^2=0.99)

Legume	Shoot biomass management			
	Removed		*Retained*	
Clitoria	5		153	(42)
Lablab	0		118	(40)
Centro	33		111	(36)
Soybean	0		99	(34)
Burgundy bean	0		25	(21)

This study demonstrated that tropical forage legumes can contribute equivalent to >100 kg urea-N/ha and triple grain yield of a subsequent maize crop. This probably represents the upper potential for legume N inputs and recovery of legume N, as irrigation enabled high legume productivity, rapid residue decomposition and high maize N demand. Hence, these yield benefits to the subsequent crop when their growth is maximised, and subsequent crop N demand is high. Tropical legume species varied in their potential to produce N for the subsequent crop. When shoot biomass was retained centro, clitoria and lablab had the largest yield benefit, and centro was the only species with a discernible N contribution once shoot biomass was removed, while burgundy bean provided little, if any, benefit.

The penalty of removing fodder is large, with no significant increase in subsequent grain yield. Hence, in hay production or cut and carry systems this is likely to greatly reduce the N benefit to the subsequent crops. This large trade-off between maximising the use of biomass for livestock fodder and translating legume N benefits to the subsequent cereal crop may be mitigated where excreta is applied to crops, under grazing or where greater residual biomass is retained and returned to the soil.

In conclusion, tropical forage legumes can provide large N inputs, however achieving substantial increases in subsequent crop production requires selection of suitable legume species, retention of legume shoot biomass and environmental conditions which maximise legume and crop productivity.

7.2.2 Legume-Maize rotation, Naibonat, West Timor (Experiment 2.2)

In the rotation experiment at Naibonat in 2015, the 4 forage legumes produced between 7.9 and 9.4 t/ha over the 165 days. This equates to an average growth rate of between 48 and 57 kg DM/ha/day over this period. *Clitoria* was the most productive legume producing significantly more biomass than lablab and Centro *cv.* Bundey. Soybean growth was very low due to rapid onset of flowering but was included further in the study to provide a comparison of the likely biomass and N contributions from a grain legume in the system.

Compared to following a maize crop the yield after legumes where biomass was retained were increased by 2.1 - 2.8 t/ha, or 82-110% in the first year, and 0.6-1.2 t/ha (20-45%) in the second year (Table 13). In the first and second maize crops sown after the legumes there was a large and persistent effect of forage legume biomass removal on subsequent crop yields and crop biomass at anthesis (Table 13). In the first year, where the forage legume biomass had been removed the grain yields were 1.6-1.9 t/ha lower than where their biomass had been retained. The difference between forage legume biomass removed and retained was reduced but still significant (0.5-0.8 t/ha) in the second maize crop after the legumes. These differences due to biomass removal also occurred after the soybean crop but were approximately half of the forage legumes associated with the lower biomass from soybean.

Despite the lower yield increases after legumes when their biomass was removed, we still saw significant increases in grain yields of up to 0.88 t/ha and anthesis biomass of up to 2.85 t/ha in the first maize crop after Clitoria compared to following maize or soybean. Maize yield and biomass was still significantly increased in the second maize crop, increasing grain yield by up to 0.43 t/ha and anthesis biomass by up to 1.2 t/ha. The maize yield and biomass increases were always highest after Clitoria and while they were less for the other forage legumes these were often still significant.

In the second year, the higher N fertilisation treatment (46 kg N/ha more) implemented in the maize control increased grain yield and anthesis biomass by approximately 1.4 t/ha. This effect was greater than the benefits observed after the legumes (retained or removed) in that season. Based on this response of 32 kg grain yield/kg fertiliser N applied, the legumes are predicted to have provided to the second maize crop < 15 kg N/ha when cut and removed, and 20-40 kg N/ha when retained. If a similar N response rate was observed in the first crop, then equivalent contribution of fertiliser N was 12-30 kg N/ha when the legumes were removed for forage and 65-85 kg N/ha when the legume biomass was retained.

Analysis of yield components of the maize crops showed that kernel mass per cob rather than cob number that was the most responsive to the additional N provided by the legumes. A clear fertiliser N and legume response was observed in the second year with higher N treatment increasing kernals per cob by 40%. This data suggests that N limitations were likely to have occurred after anthesis.

Plate 7. Comparison of productivity responses of maize crops following forage legumes (left – retained biomass, right – removed biomass). Photo courtesy of Jacob Nulik.

Table 13. Forage legume biomass production and impacts on crop yield, biomass and yield components of two subsequent maize crops when legume biomass was either retained or cut and removed from plots at Naibonat. *P* scores for treatment effects and associated least significant difference (*LSD*) are provided where there is a significant effect.

Rotation legume or crop	**Legume/crop biomass (grain) yield** (t/ha)	**Subsequent maize crops**											
		Grain yield (t/ha)				Anthesis biomass (t/ha)				Kernal mass/cob (g)			
		First year		**Second year**		**First year**		**Second year**		**First year**		**Second year**	
		Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut
Maize	6.2 (1.7)	2.51		2.84		2.23		2.05		36.5		48.4	
Maize + N[A]				4.31				3.42				69.0	
Clitoria	9.4 [a]	5.27	3.39	4.08	3.27	5.08	3.20	3.57	3.06	67.8	44.4	63.9	54.4
Centro *cv.* Cavalcade	8.6 [ab]	4.90	2.96	3.43	2.92	5.04	2.65	3.66	3.25	66.6	45.4	57.6	53.5
Centro *cv.* Bundey	8.3 [b]	4.58	2.91	3.77	3.04	3.94	1.82	3.47	2.57	65.6	46.4	65.5	53.3
Lablab	7.9 [b]	4.91	3.31	3.66	3.13	3.85	2.41	3.25	2.41	64.8	47.8	63.7	54.2
Soybean	1.4 [c]	2.68	1.86	3.07	2.80	2.03	1.41	3.03	2.05	42.8	31.5	48.5	45.8
Treatment effects		*P score*	*LSD*	*P score*	*LSD*	*P score*		*P score*	*LSD*	*P score*		*P score*	*LSD*
Rotation crop	<0.01	<0.01	0.73	<0.01	0.25	<0.01	1.19	<0.01	0.39	<0.01	9.9	<0.01	3.3
Legume removal		<0.01	0.38	<0.01	0.27	<0.01	0.62	<0.01	0.43	<0.01	8.8	<0.01	3.7
Spp. x Leg. removal		0.138		0.350		0.395		0.322		0.446		0.017	4.7

[A] Crops following maize provided an additional 100 kg urea/ha compared with the standard N fertiliser (100 kg urea/ha) in all other crops

Total soil N measured prior to the first maize crop showed significantly higher content (0.16 to 0.26 mg/g) in the soil surface layer after the forage legumes when biomass was retained compared to following maize. The retained legume treatments also had significantly higher total N content than when legume biomass was cut and removed. There was no significant difference in deeper soil layers. The degree that these total N relate to plant available N (e.g. nitrate) is unknown.

Preceding the second maize crop, significantly higher soil profile nitrate was found following several of the forage legumes compared to following maize or soybean (<50 kg N/ha). Interestingly, Centro *cv.* Bundey had similar soil nitrate content to following maize or soybean, while the other forage legumes were much higher (> 100 kg N/ha). The soil nitrate in the systems following the clitoria and Centro *cv.* Cavalcade where legume biomass retained was significantly higher than when legume biomass was removed.

Table 14. Soil surface (0-15 cm) total N and soil profile (0-60 cm) mineral NO_3 prior to sowing subsequent maize crops in the first- and second-year following forage legumes at Naibonat

Previous crop	Soil surface total N (mg/g) before first maize crop in Dec 15		Soil profile NO_3 before 2nd maize crop in Dec 16	
	Uncut	Cut	Uncut	Cut
Maize (control)	0.52		51	
Clitoria	0.78	0.61	167	98
Centro *cv.* Cavalcade	0.76	0.64	152	121
Centro *cv.* Bundey	0.62	0.56	50	42
Lablab	0.68	0.55	149	144
Soybean	0.50	0.45	46	24
Rotation effect	*P score*	*LSD*	*P score*	*LSD*
Rotation crop	<0.001	0.08	<0.001	26
Legume removal	<0.001	0.04	<0.001	23
Rot. crop x removal	0.451		0.014	29

7.2.3 Legume-Rice rotation, Mbay, Flores (Experiment 2.3)

The forage legumes produced > 5 t DM/ha over 6 months from the earlier sowing and significantly less over the shorter period (Table 15). Clitoria produced 0.7-0.8 t/ha more biomass than centro in both rotation lengths. In Clitoria, 1.5 t DM/ha was removed after 3 months in the cut treatment (leaving a residual of 0.8 t DM/ha), which regrew to achieve similar biomass at the end (5.7 t DM/ha). However, when aggregated over the whole growing period (7.2 t/ha), this was not significantly more than the uncut treatment (P = 0.22) and there was no significant effect on the subsequent rice crop.

The rice crop yield was significantly increased following the legumes in rotation for the same fertiliser inputs (Table 15). This grain yield increase was larger (1.8-2.1 t/ha) for the longer rotation of legumes than following the shorter rotation. There was no significant effect of the legume species on grain yields of the subsequent rice crop. The rice crop after legumes had the same yield as the higher fertiliser treatment that received an additional 150 kg of urea. Based on the efficiency of fertiliser conversion to grain measured here (26 kg rice/kg fertiliser N), the legumes are estimated to contribute the equivalent of 75 kg fertiliser N/ha after the 6-month rotation and 50 kg fertiliser N/ha after the 3-month rotation.

Table 15. Rice yield, biomass and crop components following either a 3 or 6 month rotation of forage legumes when legume biomass was either retained or cut and removed. Where main effects (fallow period or legume removal) are significant, the level of significance and the least significant difference is provided.

Rotation history	**Rice fertiliser N applied (kg/ha)** †	**Period 1**	**Period 2**		**Period 3 – Subsequent rice crop**	
		Rice grain yield † (t/ha)	Legume biomass[A] (t/ha)		Grain yield (t/ha)	
Rice –fallow	Low	3.69^{ab}	-		2.79	
Rice - fallow	High	4.67^{a}	-		4.60	
Clitoria	Low		5.74		4.80	
Centro	Low		5.04		4.72	
Rice - Clitoria	Low	3.23^{b}	3.34		4.21	
Rice - Centro	Low	3.28^{b}	2.53		4.07	
			P score	*LSD*	*P score*	*LSD*
Rotation history (all)					*0.001*	*0.88*
Rotation length (excl. rice)			*<0.001*	*0.55*	*0.018*	*0.50*
Legume species (excl. rice)			*0.009*	*0.55*	*0.650*	
Leg spp. x rot. length			*0.836*		*0.910*	

[A] Only uncut legume biomass are presented here to allow for fair comparisons between legumes.

† In period 1, rice crops received 200 kg urea/ha in high treatment, 50 kg urea/ha in low treatment and no fertiliser in the system preceding the legumes. In period 3, rice crops received 50 kg urea/ha in the low and 200 kg urea/ha in the high fertiliser application treatments

7.2.1Legume – maize relay and intercropping (Experiment 2.4)

In the first experiment at Soe, planting Clitoria in a relay at either 2 weeks or 8 weeks after maize sowing had no significant effect on maize grain yield (Figure 14 left). The impacts on legume biomass production were not quantified but clear impacts on legume seed yield (presented in section 7.4.3) indicate a significant cost due to the competition from the maize crop.

In the second experiment in Sumba, clitoria was either undersown into the interrow of maize at two densities (2.5 and 5 plants/m^2) or was sown at maize anthesis (relay) (Figure 14 right). There was a clear maize density effect on grain yield, with the lower density yielding about half of the higher density (1.5 vs 3.0 t/ha) maize crops. There was no significant effect of undersowing the legume on grain yield, though there was some indication that there was a small reduction in grain yield (10%) in the higher density maize crops when clitoria was sown in either a relay or companion sown. The competition from maize reduced clitoria production significantly from 2.8 t DM/ha in the legume only plots to 1.5 t/ha when grown in companion with maize at low density. Later sowing of the legume in a relay produced even less biomass.

The final experiment where maize was sown into an existing stand of clitoria which was allowed to regrow after maize sowing resulted in very low grain yields (<0.3 t/ha) demonstrating the effect of this competition for moisture could have. In the areas where the legume forage crop was removed and maintained weed free, there was higher grain yields but these were also very low (0.8-1.0 t/ha). These results are not conclusive but indicate there is a need to remove the legumes well in advance of sowing maize to allow soil water to accumulate and reduce risks in subsequent grain crops.

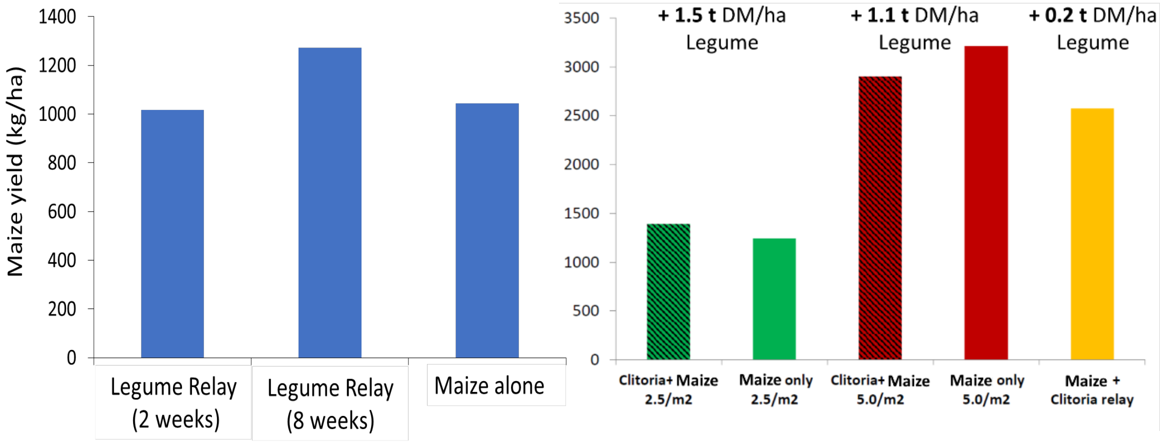


Figure 14. Maize grain yield (kg/ha) when grown alone or with Clitoria sown in the interrow in a relay at either 2 weeks or 8 weeks after maize sowing or at the same time as maize crops (hashed on right). Different maize densities were tested in Experiment 2 (right).

7.3 Livestock production impacts

7.3.1 Supplementation of Ongole cows during the dry season (Experiment 3.1)

In experiment 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 ($P = 0.06$), 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 while those fed legume hay gained 2.4 kg LW and maintained BCS over the same period.

Larger differences were observed in experiment 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. Heifers provided with clitoria hay had a significantly higher LWG (0.15 kg/day; $P < 0.01$), gaining 24.8 kg LW and 0.6 BCS units over the same period.

7.3.2 Supplementation of calves prior to weaning (Experiment 3.2)

In experiment 3, supplementation reduced mortality rates in calves provided with a supplement (0-8%) compared to non-supplemented calves (25%) (Table 16). Four calves died in the control group, one calf died in each of the clitoria hay plus 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 prior to death. All deaths occurred between late September and mid-October, which is the late dry season in this region.

LWG of calves was significantly increased in response to clitoria hay or clitoria hay plus cassava supplementation. The non-supplemented calves showed negligible or very slow growth rates, while 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 or those supplemented with the concentrate. There was also no difference in average daily LWG between male and female calves.

Table 16. Mortality rate and average daily liveweight gain of Bali calves supplemented with clitoria hay, clitoria hay + cassava, or a manufactured concentrate. Means within columns followed by different letters are different at *P* = 0.05.

Supplement type	n	Mortality (%)	Liveweight gain (kg/day)
None (control)	16	25	0.10[a]
Concentrate	14	8	0.14[ab]
Clitoria hay	13	0	0.21[bc]
Clitoria hay + cassava	14	8	0.24[c]
SEM			0.013

7.3.3 Supplementation of growing bulls (Experiment 3.3)

In experiment 4, Ongole bulls consuming clitoria had higher LWG and change in BCS and hip height compared to 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. The total feed intake and intake of CP and gross energy was higher in bulls supplemented with clitoria compared to those fed only native grass and rice straw, with a higher feed conversion efficiency (kg DMI per kg LWG) (Table 17). Bulls consumed most, but not all the clitoria offered.

Table 17. Average daily feed intake and growth of Ongole bulls fed native grass or rice straw ad libitum, with or without Clitoria for 11 weeks. Means within rows followed by different letters are different at P = 0.05.

	Diet		SEM
	Native grass / rice straw	+ Legume	
Total feed intake (g DM/kg LW.day)	20.2[a]	27.5[b]	1.00
Clitoria intake (g DM/kg LW.day)	-	19.1	0.05
Grass & rice straw intake (g DM/kg LW.day)	20.2[a]	8.41[b]	1.99
CP intake (g CP/kg LW.day)	0.72[a]	4.60[b]	0.66
Gross energy intake (MJ/kg LW.day)	0.29[a]	0.44[b]	0.02
Feed conversion ratio (kg feed intake/kg liveweight gain)	21.6[a]	9.7[b]	2.18
Liveweight gain (kg/day)	0.16[a]	0.50[b]	0.059
Change in BCS (1-5 scale)	0.4	0.6	0.08
Change in hip height (cm)	3.6[a]	4.8[b]	0.25

7.3.4 Prospects for improving livestock productivity in eastern Indonesia

The results from the livestock feeding experiments illustrate 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 South-East Asia. Traditional livestock diets in these systems are typically low in CP and ME, limiting growth, reproduction and survival. 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.

Low reproduction rates in both Ongole and Bali cows have been the primary target of recent government programs and policies to increase beef production in Indonesia. For example, the national UPSUS SIWAB program (Ministry of Agriculture regulation No. 48 / PK.210 / 10/2016) aims to increase cattle numbers through improved cow nutrition and management. While 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 during periods of nutritional stress will contribute to improvements in conception rates and inter-calving intervals through maintenance, or even increases in, LW and BCS as demonstrated in our experiments. 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 (Antari *et al*. 2014a; Antari *et al*. 2014b; Syahniar *et al*. 2012). 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 age of puberty, further contributing to increased lifetime productivity (D'Occhio *et al*. 2019).

Our research also demonstrated a role for herbaceous legumes to contribute to increased turnoff rates through increased calf survival. The mortality rate of 25% for non-supplemented calves in our experiment was similar to that reported for the Kupang district by Jelantik *et al*. (2008a) (22%). 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 as occurs during the late dry season in West Timor, provision of any additional feed can increase calf survival.

Feeding dried or fresh clitoria also increased LWG of unweaned Bali calves and older Ongole bulls. Average LWG of supplemented calves in our experiment was similar to that reported by Jelantik *et al*. (2010) (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 (e.g. 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 due to shortages in household labour. Thus, it is possible that providing herbaceous legumes to Bali cows as well as calves, whilst still utilising the creep feeding system to make sure calves have unrestricted access to feed, would result in further improvements in LWG. Improvements in animal housing and husbandry 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 approximately 20 kg LW advantage following six months of supplementation. This is significant when considering that a mature Bali cow weighs only 220 kg (Mayberry *et al*. 2016) and Bali bulls are often sold for slaughter at 260 kg LW (Dahlanuddin *et al*. 2014).

Plate 8. Fresh forage legumes being fed to Ongole bulls can increase liveweight gains by 0.35 kg LW/ha

In older, weaned animals, LWG of 0.5 kg/day in Ongole bulls supplemented with herbaceous legumes represent a significant increase in growth rates compared to non-supplemented bulls (0.16 kg/day). Despite this, LWG remains below the genetic potential for animals of similar age. The CP content of diets consumed by the bulls was estimated to be above the minimum CP content required to maximise LWG as reported by Antari *et al*. (2014c) (13% CP for young Ongole bulls). Thus, we infer that a source of additional ME is required to further increase LWG. Extra energy could be used to both 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 or maize bran (e.g. Dahlanuddin *et al*. 2013, 2014; Quigley *et al*. 2009).

The feeding value of herbaceous legumes could also be improved through method of preparation. In cut and carry systems, the whole legume plant will be fed. Jones *et al*. (2000) showed that the N content of leaves of clitoria and other herbaceous legumes was approximately twice that of stems. The reverse was true for fibre content. If the plant is fed in its whole form, animals (particularly small ruminants) may be able to select higher quality leaves from the feed provided. Where legume is chopped to minimize waste and make it easier for calves to consume, it is difficult for animals to select the high-quality leaves from the stems. The process of drying legume for hay can also impact feeding value, with leaf loss higher in over-dried hay.

While some small-holders 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, most farmers will not be able to grow enough legume to supplement all their livestock and will have to make management decisions about which livestock class to give the legumes to (i.e. unweaned calves, growing animals or cows of reproductive age). While feeding strategies will be influenced by a range of factors including production system, household labour resources, livestock prices, and local market demand (Gabb 2017), our research provides some general indications of how herbaceous legumes can be used in small-holder cattle production systems. The combination of different feeding requirements for different livestock classes and legume production system will influence the land area required to produce sufficient legume biomass. This suggests that permanent legume stands are best suited to systems focused on the growing and fattening of bulls, which have high nutritional demands but are also more likely to fetch good market prices (Table 18). Clitoria grown as a companion crop in a relay with grain crops have lower biomass production potential but may provide sufficient biomass to improve cow reproduction and/or increase the survival and LWG of young calves (Table 18), so are very suitable for 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.

7.3.5 Comparison of herbaceous legumes to 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 inputs or cost. In comparison, the cost of concentrate feeds makes them inaccessible for cash-poor small-holder farmers, and they are not always readily available in the market. These barriers to supplementary feeding are clearly illustrated in the case of calf supplementation in West Timor: Jelantik *et al*. (2008b) demonstrated the benefits of supplementing unweaned Bali calves over ten years ago, yet there has been no uptake of feeding concentrate to calves, and growth rates and calf survival rates remain unchanged. With the right support for small-holders and consistent access to seed stock, the use of legumes for feeding of calves and other livestock should be more widely adopted. In a similar project in Laos, Monjardino *et al*. (2020) evaluated the use of herbaceous legumes in a rice-legume system and predicted a peak adoption of legumes for livestock feeding of 54% within 6 years. Similar adoption rates should be achievable in eastern Indonesia.

In addition, feeding purchased concentrates may not provide any production advantage over home-grown feeds. In the calf feeding experiment (experiment 3), higher LWG was observed in calves supplemented with clitoria hay (with or without additional cassava, 0.23 kg/day) compared to the calves fed the concentrate supplement (0.14 kg/day). While we do not have data to indicate whether the amount of supplement consumed was a factor, the results are consistent with Quigley *et al*. (2009), who reported that supplementing Bali calves with tree legumes resulted in similar LWG to 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*. (2014a) found that there was no LWG advantage in using expensive, purchased supplements such as onggok (a cassava by-product) compared to tree legumes, which can be grown for little or no cost.

Feed quality, and therefore LWG of cattle fed either herbaceous or tree legumes are generally comparable. This is illustrated in feeding experiments conducted as part of the previous ACIAR project, where researchers compared liveweight gain of young Bali bulls fed native grass supplemented with either clitoria or leucaena and found no significant different in LWG (Dalgliesh 2012). The biggest differences between herbaceous and tree legumes is how they are integrated into farming systems. Tree legumes such as sesbania and gliricidia 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*. 2017; Dahlanuddin *et al*. 2014), 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 prior to the first harvest. In 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.

Table 18. 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 (Lindsay Bell, unpublished data). Areas of legume required are rounded to the nearest 0.1 ha.

	Livestock type				
	Mature Ongole cow	**Mature Bali cow**	**Growing Ongole bull**	**Growing Bali bull**	**Unweaned Bali calf**
Features of livestock feeding system					
Animal liveweight (kg)	340	220	250	150	50
Amount of legume to feed (g DM/kg LW.day)	10	10	20	20	20
Purpose of feeding legume	Maintain liveweight during dry season	Maintain liveweight during dry season	Increase liveweight gain	Increase liveweight gain	Increase liveweight gain 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 production system and indicative yields	**Area legume planting required (ha) for each livestock x production system type**				
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
- rotation (1.5 – 4 t DM/ha)	0.2 – 0.4	0.1 – 0.3	0.4 – 1.0	0.3 – 0.7	≤ 0.1
- intercrop/relay (0.5 – 2.5 t DM/ha)	0.2 – 1.2	0.2 – 0.8	0.6 – 2.9	0.4 – 2.2	0.1 – 0.4
Irrigated					
- permanent stand (6 - 9 t DM/ha)	≤ 0.1	≤ 0.1	0.1 – 0.2	0.1 – 0.2	≤ 0.1
- relay/rotation (4.5 – 7.5 t DM/ha)	≤ 0.1	≤ 0.1	0.2 – 0.3	0.1 – 0.2	≤ 0.1

7.4 Seed production research and development

The seed production experiments conducted in northern Australia and eastern Indonesia demonstrated clear differences in the flowering behaviour between the main forage legumes of interest (clitoria, centro and lablab). Responses to photoperiod differed between northern Queensland (17°S) and eastern Indonesia (10°S) indicating these are important in some of these species (particularly lablab). The use of trellising systems best increased flowering and seed production in clitoria, and there is good potential to integrate traditional maize grain production with clitoria seed production as an inter-crop. The research in ENT was conducted without the use of supplementary fertilisers or irrigation, except to encourage establishment where low rainfall may have compromised an experiment.

7.4.1 Location and sowing date effects on flowering (Experiment 4.1)

Sowing time influenced the period from sowing to the onset of flowering for all of the legumes studied as vigorously growing, spaced plants in north Queensland (~17°S) (Table 19). However, the magnitude of the effect varied considerably between the four species: Bundey and Cavalcade centro and Highworth lablab had flowering patterns indicative of strong 'short-day' responses for flowering (*i.e.* flowering earlier when sown closer to the onset of short days); whereas Milgarra clitoria and Juanita burgundy bean flowered readily regardless of sowing date, but the period to the onset of flowering was delayed at cooler periods of the year ('day-neutral' response). Bundey centro flowered approximately 3 weeks later than Cavalcade. These responses are consistent with previous reports for these species grown in northern Australia (Cook *et al*. 2005) and indicate there is more flexibility for sowing time when considering seed crops of Clitoria and Burgundy bean compared to Highworth lablab, and Centro cultivars.

Daylength had a lesser effect on the time to onset of flowering in legumes at lower latitudes (~10°S) in eastern Indonesia and onset to flowering was considerably earlier in 'day-neutral' Clitoria than when grown in the upland north Queensland environment (Table 21). The 'short-day' flowering response in Bundey centro remained strong in eastern Indonesia, whereas sowing time between February and June had relatively little effect on the period to onset of flowering in Highworth lablab. Dalrymple vigna showed a strong short-day response for flowering (data not shown). Both upland and lowland sites appeared suitable for seed production, although the onset of flowering tended to be delayed in upland compared to lowland sites.

7.4.2 Trellising effects on flowering and seed production (Experiment 4.2)

Simple pole trellises increased the number of reproductive nodes produced in the 6 (summer) to 8 (winter) months after sowing by 48 to 91% in spaced Milgarra clitoria plants grown in north Queensland (Table 20), but had no measurable effect in the centro, lablab and burgundy bean cultivars (data not presented). The effect was strong at all sowing times, but greatest when the plants were grown over the warmer spring and summer periods under irrigation. Trellis effects on flowering continued through to pod and seed production with the November sown plants grown with trellises having 53% greater pod weight (from 51% more reproductive nodes) than plants grown without trellises (data not presented).

The use of trellises on Milgarra plants grown in plots in eastern Indonesia during 2015 and 2016 also increased the number of reproductive nodes, but the responses were less (no response up to 64% increase) than observed in north Queensland (Table 21). The Indonesian grown plants were, however, considerably smaller and less actively covered the trellises than the north Queensland plants having been grown without fertiliser or irrigation to supplement rainfall (the plants grown at the upland site at Tobu grew the most vigorously and had the greatest response to flowering). Although not captured by the data, the use of pole trellises enables easier harvesting (hand picking pods) within small-holder systems as the pods are more concentrated and presented higher than for field crops. The presence of pole trellises had no effect on the period from sowing to flowering for all legumes studied in north Queensland or Indonesia.

The comparison of the use of pole and traditional unfertilised maize (2.5 plants/m^2) trellises at Soe during 2016 compared to a field crop (at the same clitoria planting configuration) showed pole trellises can increase clitoria seed yield by 31% (and pod number by 37%, data not presented) compared to a field crop. Using maize as a trellis produced similar clitoria seeds yields to the field crop (Figure 15). Integrating clitoria and maize at a plant spacing of 2.5 plants/m^2 did not affect maize grain yields compared to growing maize as a monocrop: mean maize grain yields ranged from ~1.0 to 1.2 t/ha (data not presented).

Table 19. Effect of time of sowing on the days and growing degree days (GDD) to flowering of spaced plants of selected forage legumes grown in north Queensland.

Period of crop cycle	Days[2] (GDD)[3]	Centro cv. Bundey *Cavalcade*	Clitoria	Highworth Lablab	Burgundy bean
25 Nov 2013 - 6 June 2014	193 *(4575)*	148 c *122* b	68 a	124 b	93 a
7 April 2014- 10 Dec 2014	247 (5180)	64 a	184 c	87 a	117 b
29 Aug. 2014 - 10 Mar. 2015	193 (4692)	DNF	99 b	DNF	99 a
F-statistic		<0.001	<0.001	<0.001	<0.001

[1] Means with the same letter are not significantly different (P=0.05): DNF = did not flower; [2] Days over the monitoring cycle (days)

Table 20. The influence of pole trellises on the days to flowering (DF) and total number of flowering nodes per plant (FN) for spaced Clitoria plants grown in north Queensland.

	25 Nov 2013 - 6 June 2014 (193 days/4575 GDD[2])		**7 April 2014- 10 Dec 2014** (247 days/5180 GDD)		**29 Aug. 2014 - 10 Mar. 2015** (193 days/4692 GDD)	
	DF	**FN**	**DF**	**FN**	**DF**	**FN**
Without trellis	67.1	289.7 b	192.1 b	62.7	99.3	105.1
With trellis	68.7	439.5 a	180.3 a	92.9	99.8	201.2
F-statistic	0.391	0.012	0.03	0.082	0.719	0.004
Trellis effect (%)	+51.7		+48.2		+91.4	

[1] Means with the same letter are not significantly different (P=0.05): [2] Growing degree days: total daily mean temperature (°C)

Table 21. The influence of location, sowing date and simple pole trellises (*Clitoria ternatea* only) on the days from sowing to flowering (standard error) of selected forage legumes grown in eastern Indonesia.

Site	Sowing date (2015)	Bundey Centro	Highworth Lablab	Clitoria (no trellis)	Clitoria (with trellis)	Trellis effect on clitoria flowering (%)
Kupang	27 Mar.		47	42	42	-6.4
	20 Apr.[1]	77				
	27 May	44	51	46	46	+15.6
	27 Aug.	-	-	49	50	+12.2
Soe	4 Feb.	142	66	70	66	
	9 April	105	77	109	76	
Tobu	11 Feb.	90	75	70	60	+63.5
	2 April	84	64	62	55	+29.0
	8 June	66	61	59	53	+58.2
Ende	30 Mar.	54	Poor growth	75	78	+16.0
	15 May	35	Poor growth	96	105	-5.9
	30 June	55	Poor growth	Poor growth	Poor growth	UD
	15 Dec.	114	Poor growth	114	63	+15.8

[1] Re-sow due to insufficient plant population when sown on 27 March
[2] UD = unreliable data due to poor growth or damage after the onset of flowering

7.4.3 Integrating clitoria seed and maize grain production (Experiment 4.3)

The experiment in 2016 at Soe indicated there was good potential to produce clitoria seed and maize grain within the one system. However, only a low population (2.5 plants/m^2) of maize was tested and the experiment represented only one growing environment (upland vertisol). It was decided to complete another experiment in 2017 at a lowland site on Sumba using maize populations 2.5 and 5.0 plants/m^2 with clitoria at the same spacings. Growth was more vigorous in this environment than at Soe. Clitoria flowering began in March and continued until the end of the experiment in October. Total clitoria inflorescence number (weekly counts) was only slightly reduced by the presence of maize (both population densities) when both were sown mid-February but was lower when clitoria was sown as a relay at the end of March (Figure 16). Total hand-harvested (April to October) clitoria seed yields showed a similar relationship. Mean cleaned clitoria seed yields ranged from 550 to 740 kg/ha when sown in February, regardless of maize population, and was 300 kg/ha when clitoria was sown at maize anthesis. Although not affecting clitoria seed yields, an increase in maize population from 2.5 to 5.0 plants/m^2 increased main grain yield from ~1.2 to over 3.2 T/ha. This results from this experiment indicate traditionally managed maize and clitoria can be grown together with relatively little reduction in the yields of either crop.

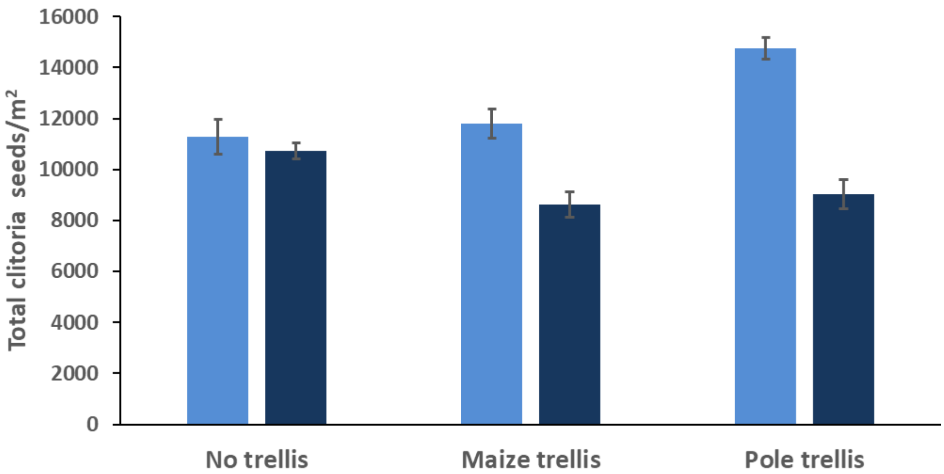


Figure 15. The effect of trellis type and sowing time (light blue – at maize sowing, dark blue – at maize anthesis) on clitoria seed yield recovered by hand harvesting between July and October 2016, Soe. Maize was sown on 14 January 2016 at 2.5 plants/m^2 using local crop management methods and clitoria at 40 x 20 spacings.

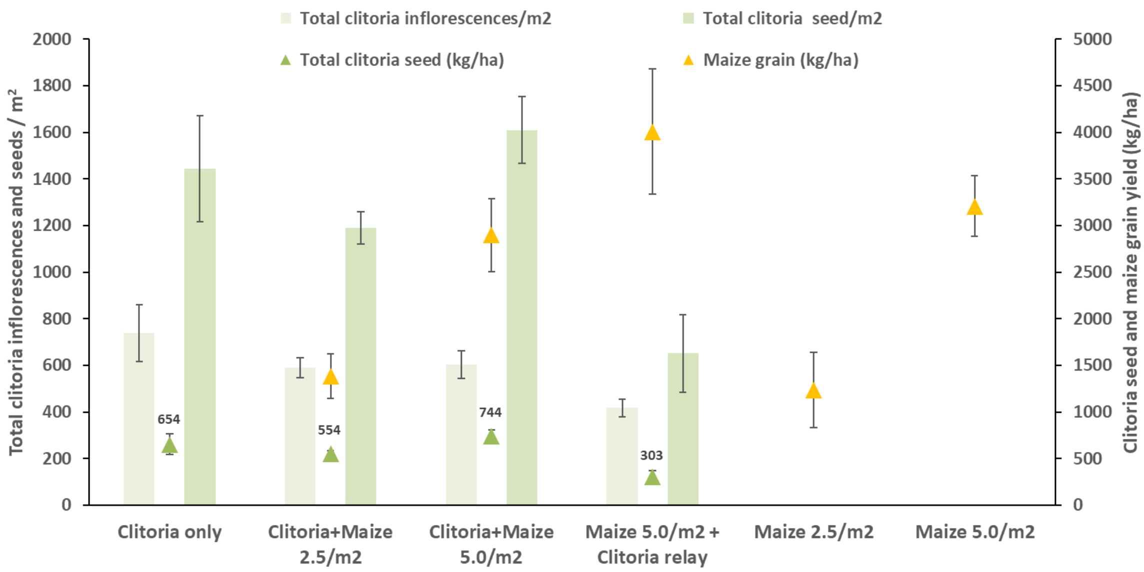


Figure 16. The effect of maize population density and timing of sowing on hand-harvested clitoria seed and maize grain yields when grown as an intercrop, Sumba 2017. Maize was sown on 14 Feruary 2017 and clitoria at maize planting and maize anthesis (30 March).

7.4.4Development of seed production networks and systems

Seed production of herbaceous legumes has been undertaken concurrent with the research program mostly to supply seeds for research and government extension programs in ENT. This has been coordinated by BPTP ENT and includes in-village and government research station production. Anticipated increased demand for seed following the promotion of research results has led to the selection of a new clitoria line by BPTP ENT (seeking registration) enabling sale to meet Indonesian trading regulations. This will complement farmer to farmer sale of the original clitoria line.

Clitoria has the most potential for use in cattle/grain crop systems in ENT and importantly for adoption, seed production has been shown to be relatively reliable and flexible. There is no obvious photoperiodic requirement for flowering meaning a seed crop can be grown all year provided growing conditions (temperature and soil moisture) are suitable. This means crops can be grown, for example, over the wet season where there may be dry season limitations to growth, or during the dry season in rice paddies after harvest. Clitoria also regrows well after cutting providing the opportunity to combine fodder production with seed production or produce multiple seed crops over the year. Seed can be produced in a range of locations in ENT (upland and lowland) and harvesting and processing is easy because seeds are large, readily accessible within the crop and pods do not readily shatter (dehisce) meaning a large proportion of the crop can be recouped. Farmers can readily harvest and store their own seeds and yields and prices are acceptable. The capacity to climb means trellising can be used to improve seed yields and there appears to be good potential to intercrop with maize.

Coordination of seed distribution networks

Seed production of herbaceous legumes, principally clitoria, has been coordinated mostly by the BPTP ENT staff involved in this project (Figure 17). Seed production was originally conducted on BPTP research stations near Kupang by BPTP staff, but was progressively moved into villages with BPTP providing support (seeds and advice) on West Timor and subsequently to Flores and Sumba (Figure 17). A key role has been connecting farmers with seed users (eg DINAS) and unofficial seed testing. The distribution of seeds was initially to support our research activities and on-farm demonstrations (~40% of seed distributed). However increasingly seeds have also been distributed to universities (e.g. Nusa Cendana), Bupati, FAO and other NGOs in ENT (Figure 17). Growing interest in herbaceous legumes has resulted in clitoria seed being distributed to other regions of Indonesia including NTB, east and west Java, Sumatra and Kalimantan. Seeds were also sent to Timor Leste. The price to farmers has settled on ~30 to 35 000 Rp/kg. Demand for seeds from these regions is expected to increase in future.

BPTP ENT have developed the basic facilities to support the production and distribution of herbaceous legumes. This includes the equipment required for seed testing (staff have received training), a pest-free store for bulk seeds and freezers for the storage of early generation seed lots. Irrigated cropping land is available at Naibonat and non-irrigated land nearby at Lili. Technical BPTP staff were provided training in tropical pasture seed production in north Queensland in the previous ACIAR project.

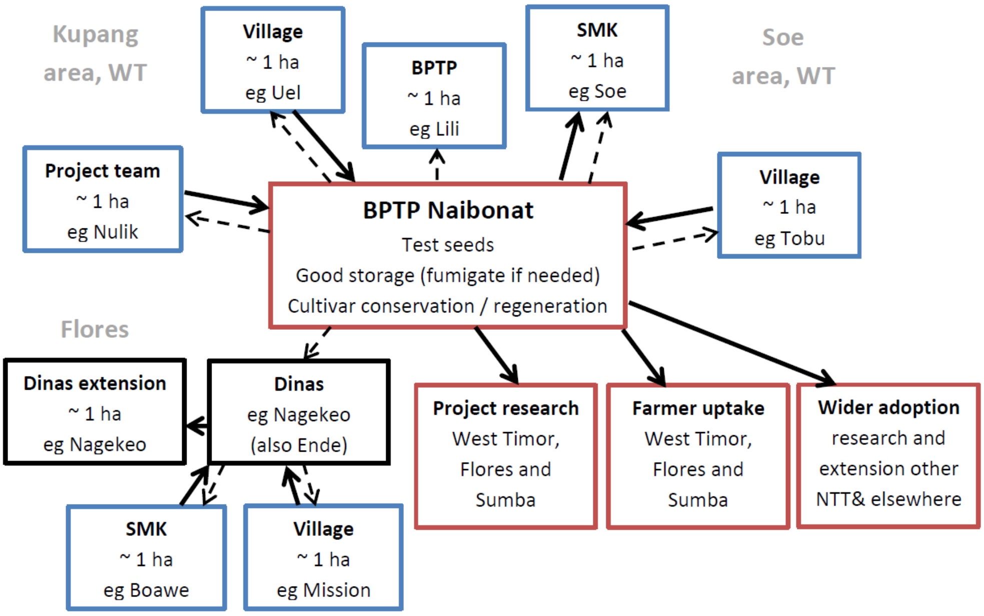


Figure 17. The role of BPTP ENT to support the production and distribution of herbaceous legume seeds within the earlier stages of the project.

Up-scaling seed production

A significant increase of forage legume sowing (clitoria and leucaena) to support the DINAS livestock distribution scheme is anticipated for 2020+. A budgeting exercise was completed by the livestock department of DINAS to determine the amount of seed required to meet DINAS needs: a total of 2000 kg for 2020, of which 1000 kg is to be clitoria. It is anticipated ~500 kg will be distributed to West Timor and 500 kg each to Nagekeo and Flores. The need for forage legume seeds (clitoria and leucaena) is expected to be on-going and a minimum of 2000 kg/year. The seeds will be distributed to 22 districts with the expectation that approximately 10 ha will be established in each district. This is expected to service the needs of 500 to 1000 farmers in ENT (1-2 kg /farmer). A conservative increase of 20% per annum has been estimated until 2025.

Although the production of herbaceous legume seed is mostly anticipated to support government cattle development schemes, seed will also be required for adoption by other farmers and agencies. There appears to be growing demand for seeds and some seed growers have begun to sell seed privately. It is difficult to quantify this trade, but farmers near Kupang have reported high prices (~50 000 Rp/kg) for clitoria seeds.

Upscaling of seed production will logically require involvement in the formal seed market. Seed for selling requires registering a variety and abiding by official seed certification and seed testing processes. Seed of unregistered lines can also be grown by farmers for their own use and sold without the need for testing or certification. The clitoria line(s) grown previously in ENT are considered to have originated from the public Australian variety Milgarra, which is a composite line and ineligible for official seed for selling. BPTP are in the process of developing a new clitoria line suitable for registration and a draft seed production strategy for BPTP was developed towards the end of the project (this can be provided upon request). This strategy describes the procedures required to support the production of early generation seeds of a new cultivar and includes an audit of BPTP facilities at Naibonat. The development of a private capacity to produce, promote and distribute seeds is a logical next step for disseminating clitoria seed to meet the expected demand increase following promotion through the upcoming BPTP and DINAS activities. It seems logical that BPTP staff should continue to provide technical advice to any agencies seeking to undertake commercial production.

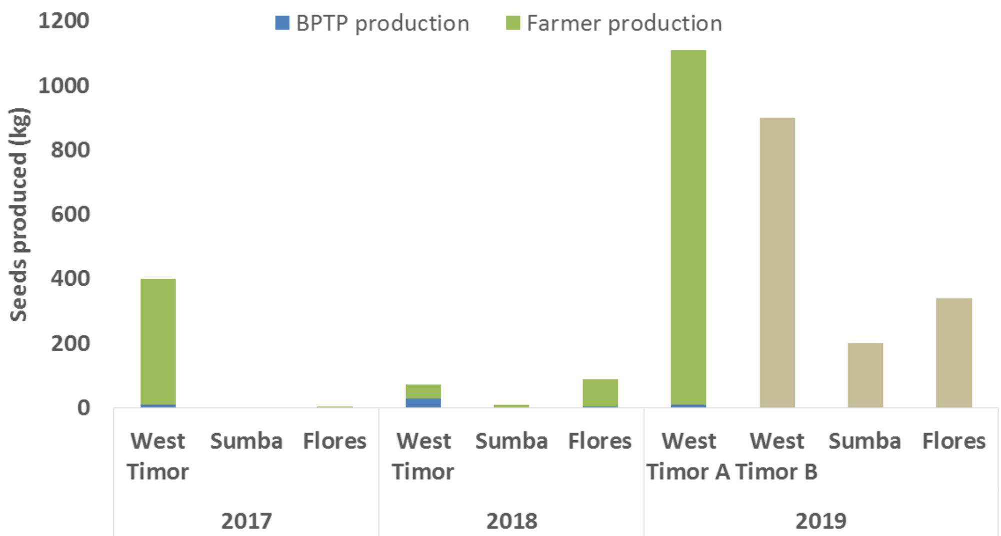


Figure 18. Historical collation of seed collected and distributed by BPTP and the sources of clitoria seed. 2019 values are estimates based on anticipated seed production areas. Columns in grey represent anticipated yields of seeds for farmer-to-farmer trade or own use based on areas planned through the DINAS cattle distribution program.

7.5 Socioeconomic impacts and participatory evaluation

7.5.1 Economic impacts of forage legumes vary with legume management & herd size

Case study farms

IAT modelling for six case study farms demonstrated that farmers relied heavily on native pastures, with native pasture in baseline scenarios accounting for 42-82% of fodder intake. This heavy reliance on native pastures was due to a lack of forages and crop stover, which was sufficient to provide fodder for only 1-5 months. Importantly, intake of high-quality fodder such as leucaena and grain legume stover was also low, with 1-13% of legume dry matter (DM) in baseline diets for all farms. Importantly, APSIM simulations for clitoria, that were used in IAT simulations, showed that the impact of forage legumes to address this feed gap varied with legume management, soil type and climate (Table 3).

Table 20. Simulated mean clitoria dry matter (DM) production when grown in a maize-forage legume relay, maize-forage legume rotation or as a permanent stand. Range is presented in parenthesis.

		Forage legumes (clitoria t DM ha^{-1} $year^{-1}$)					
Elevation (m ASL*)	Village	Relay		Rotation		Permanent	
Lowland (<300 m)	Manulai	2.4	(1.2-3.5)	4.7	(3.6-5.7)	4.1	(3.0-5.8)
	Uel	2.6	(1.6-3.8)	4.8	(4.2-5.5)	4.2	(3.1-5.7)
Midland (300-600 m)	Ekateta	1.8	(0.7-2.4)	3.7	(2.9-4.3)	3.2	(2.0-4.5)
	Camplong	1.8	(0.5-2.9)	3.7	(3.1-4.7)	3.3	(2.2-4.7)
Highland (>600m)	Oenai	2.7	(2.2-4.1)	4.8	(4.3-6.5)	4.4	(2.3-5.9)
	Kesetnana	3.4	(2.3-4.8)	6.1	(3.8-6.7)	5.6	(2.3-6.1)

** ASL, above sea level*

Achieving substantial economic benefits requires forage legume management that maximised financial returns and minimises food self-sufficiency trade-offs. Results show that, where possible, forage legumes are best managed as a permanent stand on uncultivated land, but integration via relay systems is the best alternative where land is constrained (Figure 4). Planting all uncultivated land (maximum 1 ha) to a permanent stand of forage legumes increased household income by 2-6% for farms with small herds (<2 TLU, 0.2-0.6 ha planted; TLU, tropical livestock unit 250 kg liveweight) and by 22-28% for farms with larger herds (>2 TLU, 1 ha planted). Although a maize-forage legume relay had substantially lower economic benefits, for farms where all land was cultivated (i.e Kesetnana) a relay provided the largest economic benefit.

Importantly, replacing maize with forage legumes (i.e. maize-forage legume rotation or a permanent stand replacing maize; not shown) had a large negative impact on farm returns, with net financial losses or limited economic benefits experienced across all farms. This was particularly important for small herds (1 TLU, Uel and Oenai), as the increase in livestock income from introducing forage legumes didn't cover the cost of maize grain replaced by legumes. In fact, if all the maize was permanently replaced with forage legumes, average annual farm income was reduced by 23% at Uel and 52% at Oenai. Hence, forage legume systems that maintain or increase maize production are best. This is particularly important in West Timor, given <30% of rural households are food secure and thus farmers need to produce food crops on all or most of their arable land (FAO *et al*. 2010).

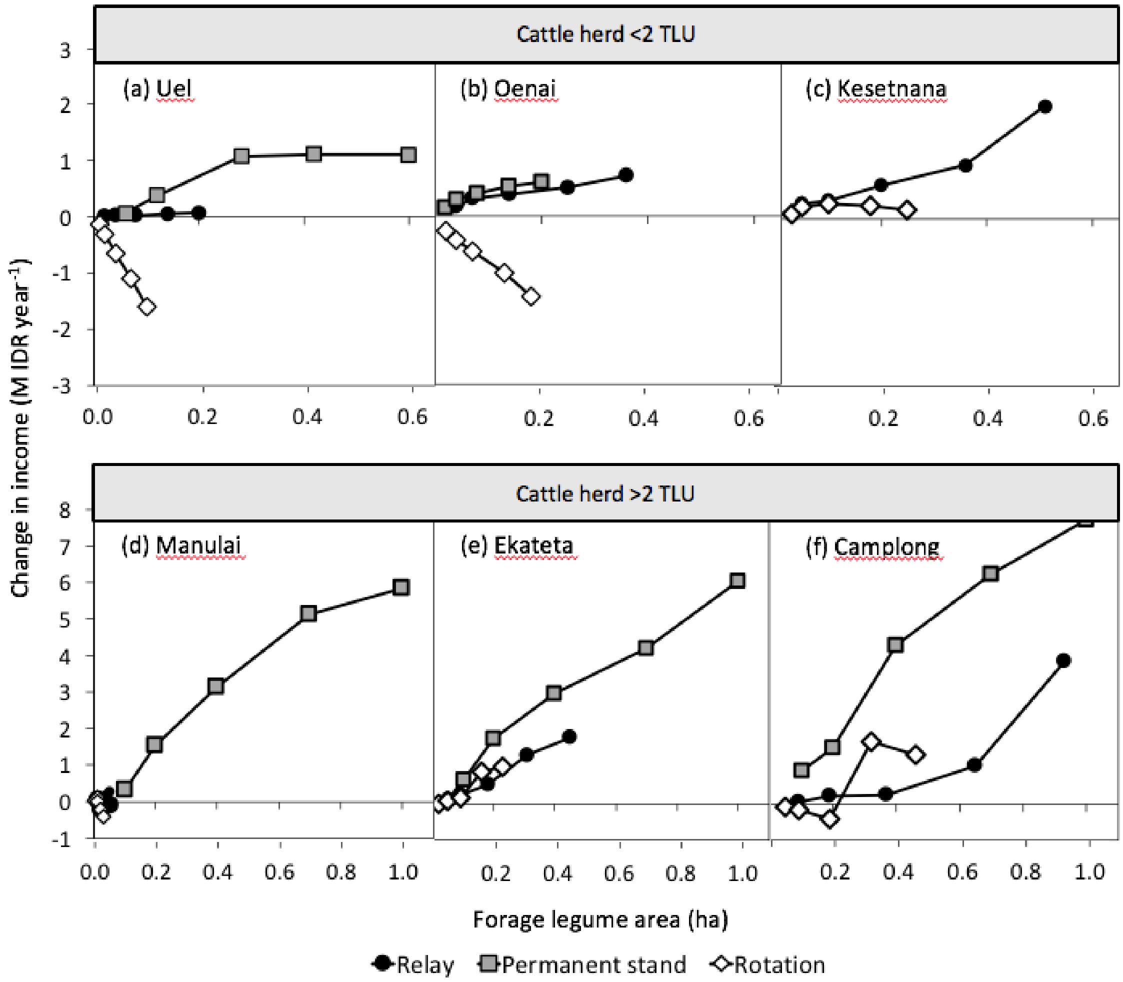


Figure 19. Impact of legume management and area on net income accounting for losses in maize production when legumes are grown as a maize-forage legume relay (circle), a permanent stand on uncultivated land (square) and a rotation (diamond). TLU, Tropical Livestock Unit 250kg liveweight.

There were larger economic responses to increasing areas of forage legumes for larger herds (>2 TLU) than for small herds (<2 TLU) or when livestock ownership was increased (Figure 5). For farmers with one animal (1 TLU), there was little or no economic response above 0.3 ha of a permanent stand of forage legumes, as the 30% threshold for legume intake had been reached. Thus, for herds with 1 TLU, 0.3-0.4 ha of forage legumes are required to maximise economic returns at 1-1.6 M IDR year^{-1}. In comparison, for herds with >2 TLU, 0.7-1 ha was required to achieve the maximum net return of 6-7 M IDR year^{-1} under current land constraints.

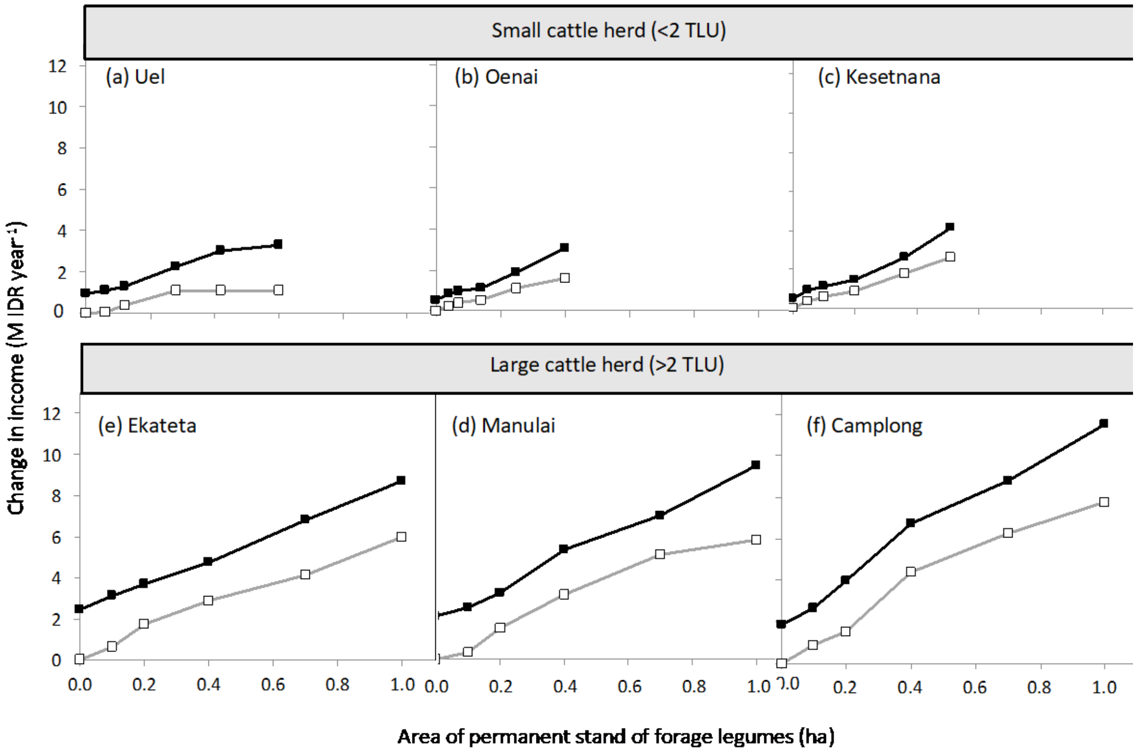


Figure 20. Change in net income (M IDR year^{-1}) in response to increasing areas of a forage legume permanent stand for baseline herd size (white squares) and baseline herd size + double bull numbers (black squares) for six case study farms in West Timor, Indonesia. TLU; Tropical Livestock Unit, 250kg liveweight.

The impact of using forage legumes to address such feed gaps is determined by the marginal value of feed, which is a factor of both feed supply and demand. This case study analysis showed that the marginal value of feed was higher for larger herds (>2 TLU; 1.8-3.1 M IDR t^{-1} TLU^{-1}) than for small herds (<2 TLU, 0.9-1.0 M IDR t^{-1} TLU^{-1}). In part, this was because the baseline diet of smaller herds was higher quality (8-13% legume biomass) than for larger herds (1-7% legume biomass), thus the feed gap for smaller herds was filled more rapidly. To illustrate, for a large herd with 8 TLU, each 1% increase in the amount of legume in the diet up to 30% resulted in an additional 1 M IDR year^{-1}, while each 1% increase in legume consumption for a herd of <2 TLU increased income by 0.04-0.1 M IDR year^{-1}.

Farm type analysis

Given the case study results, the impact of a maize forage legume relay and a permanent stand of forage legumes on uncultivated land was simulated for the 46 participating households who owned an area of dryland. As expected, larger economic benefits were achieved for a permanent stand on uncultivated land than for a maize-forage legume relay (Figure 6). For example, for *livestock focused farmers with wet and dryland* a maize forage legume relay increased whole farm income on average by 1.2 M IDR/year compared with 4.2 M IDR/year for a permanent stand. Importantly, the response to forage legumes was primarily driven by livestock ownership, with a similar economic response for farm types with similar herd sizes (i.e. *livestock focused dryland only* and *livestock focused wet and dryland* farm types).

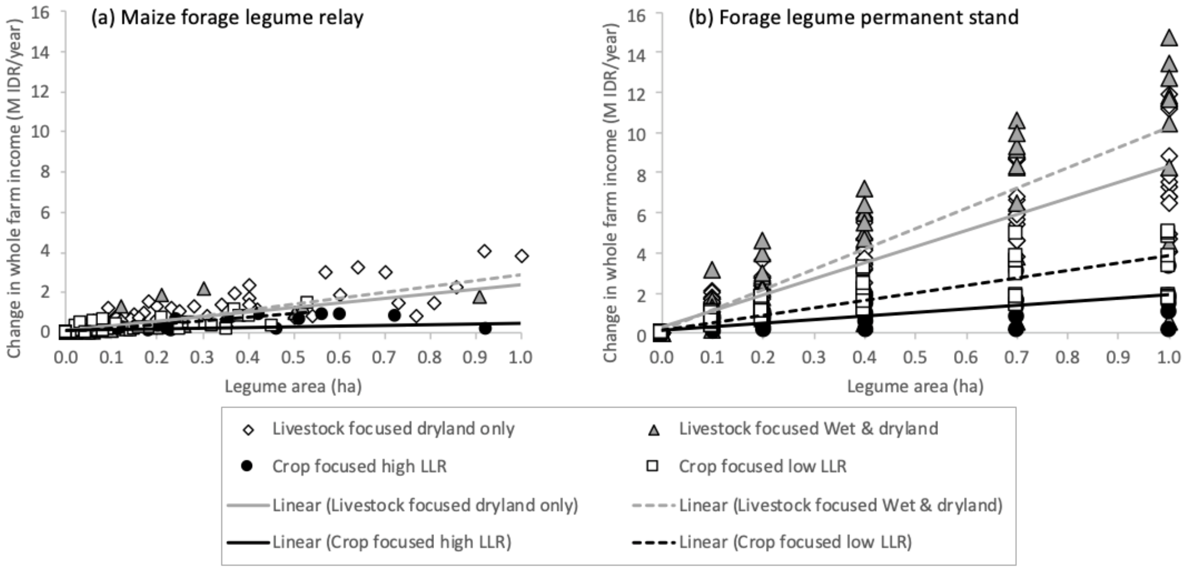


Figure 21. Change in whole farm income (M IDR/year) in response to (a) maize-forage legume relay and (b) a permanent stand of forage legumes on uncultivated land for 0.1-1.0 ha of forage legumes for individual farmers (n=46) in West Timor.

There was a strong relationship between herd size, forage legume area and the economic benefit received from forage legumes (Figure 7). As with the case study analysis, Figure 7 demonstrates that small herds (≤2 cattle) will only receive a small economic benefit (<2.5 M IDR/year) even when large areas of forage legumes are planted. In comparison, larger herds can achieve substantial economic benefits, especially when larger areas of forage legumes are planted. While herd size is the primary determinant of the economic response, simulations were also influenced by differences in forage legume production across agroclimatic zones (Table 3), the amount of crop stover available for livestock and the area of forages and native pastures available for grazing or cut and carry fodder.

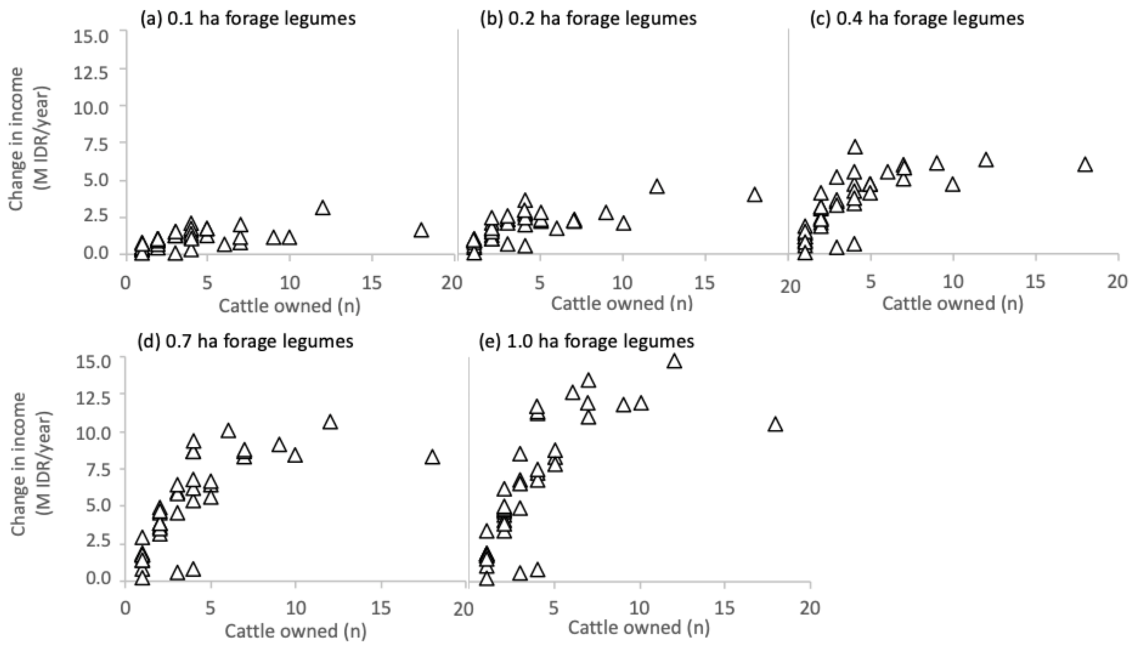


Figure 22. Chance in whole farm income (M IDR/year) in response to a permanent stand of forage legumes (0.1-1.0 ha) on uncultivated land for farmers in West Timor with herd size that ranges from 1-18 cattle.

Modelling of case study farms (n=6) as well as a broader range of farm (n=46) in West Timor demonstrated that forage legumes can provide large production and economic benefits in small-holder crop-livestock systems. However, the level of the economic benefit achieved on farm depends on herd size, resource availability – notably land and labour (area able to be managed) – legume management and production preferences. At current prices, management options that maintain staple crop production by integrating forages with food crops or using uncultivated land are the only economically viable options. For farm types, livestock focused farmers with sufficient incentive, land, labour and capacity to invest are likely to receive the largest economic benefit from forage legumes. Despite this, quantification and disaggregation of labour inputs is required to understand the potential social and economic impacts for male and female farmers. At the same time, future research should also consider the class of livestock and time of year when targeted feeding of forage legumes has the largest benefit as well as the complementary opportunities to use other improved forages such as tree legumes.

7.5.2 Benefits, constraints & management preferences vary with gender

Results from on-farm evaluation and focus groups indicate that the perceived benefits and constraints of introducing forage legumes into small-holder crop-livestock systems differs with gender and farm type. For women, the perceived key benefits of forage legumes were high quality palatable fodder, soil fertility and reduced labour inputs for fodder collection, while men focused more on fodder and increasing livestock production (Figure 5). As forage legumes could be planted close to the house and were fast to collect compared to tree legumes, participants estimated they could reduce cut and carry labour requirements from 4 hours/day to 1 hour/day. In contrast to tree legumes, forage legumes were considered easy enough for women, children and elderly to collect.

While forage legume fodder production was identified as an important benefit by both men and women, the importance of this fodder differed with farm type. *Livestock Focused* farmers indicated that fodder production and labour savings were the most important potential benefits while, in comparison, *Crop Focused* farmers indicated that potential improvements in soil fertility, land utilisation and income from seed sales were the most important benefits. This indicates that, while farmers value the potential multiple benefits of forage legumes, the perceived value of these benefits differs with farm type.

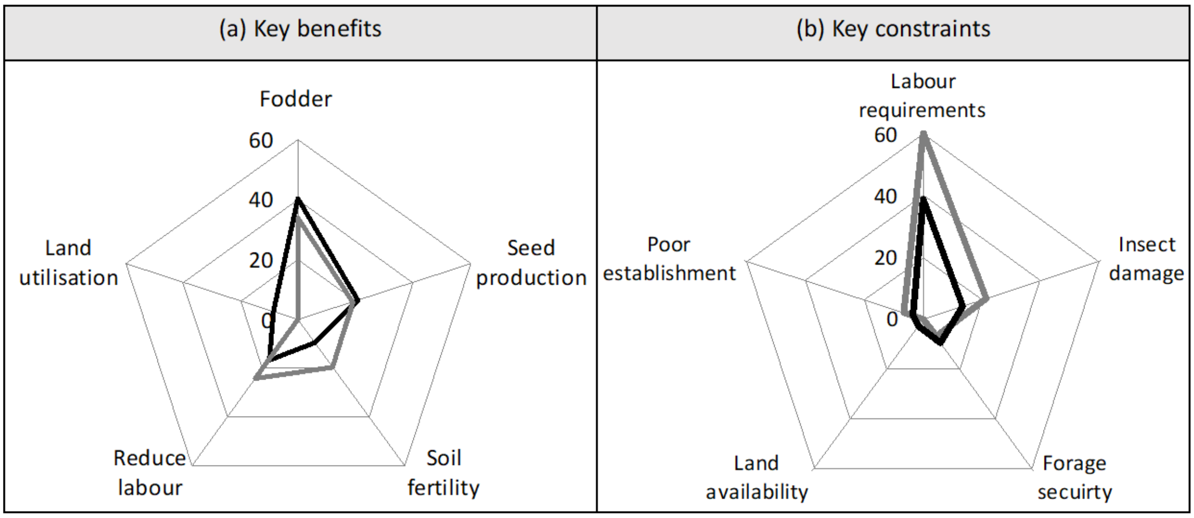


Figure 23. Key benefits (a) and constraints (b) of forage legume production identified by women (grey) and men (black) at 6 villages in West Timor after two years growing forage legumes.

Although participants indicated that forage legumes could reduce cut and carry labour, labour for land preparation, planting and weeding was the key adoption constraint. This is because the optimal time for establishing forage legumes is when farmers are busy with staple crops. Consequently, participants indicated that the earliest opportunity for planting forage legumes would be near the end of the wet season, when the risk of poor establishment is high. Importantly, unequal distribution of labour indicated that forage legumes may increase women's labour inputs – women are responsible for planting and weeding and may increase their contribution to cut and carry labour – and decrease men's labour requirements, given their responsibility for fodder collection.

For forage legume management, clitoria was favoured over annual lablab as the perennial growth habit reduced labour inputs as, if well managed, it only requires replanting every five years. Correspondingly, men preferred to plant forage legumes as a permanent sole stand (52%) or with tree legumes (17%), indicating these options decreased labour for weeding and fodder collection while increasing biomass production. In comparison, women (62%) often preferred maize-forage legume relays due to the perceived soil fertility benefits, as well as the potential to increase land use efficiency and reduce land preparation and planting labour requirements. For fodder management, farmers indicated forage legumes would be used to fatten bulls, as they received more immediate financial returns than when forages were fed to cows and calves or used as a green manure to boost crop yields and/or reduce fertilizer inputs. Despite this, no participants had observed increased liveweight gain as they were yet to produce sufficient levels of biomass to achieve production benefits.

Thus, socially constructed gender roles determine the distribution of forage legume impacts, with unequal impacts on household members likely to hamper adoption unless there is a reallocation of labour or the development of labour-saving technologies. At the household level, farmers with high land:labour ratios may also not be able to cultivate additional land with current labour endowments and may instead prefer to increase labour efficiencies by increasing the productivity of already cultivated land. While this provides opportunities to develop forage legume management strategies that minimise labour inputs and increase land productivity, feedback from male and female farmers indicates that a range of management options should be provided as management preferences vary with gender and farm type.

7.5.3 The comparative value of legume technologies differs with gender and farm type

Given the constraints identified for forage legume production, the comparative advantage of grain, tree and forage legumes were assessed. Key findings indicate that, for the majority of farmers, grain (cowpeas) or tree legumes (leucaena) were favoured over forage legumes. Preferences for legume technologies reflected both production objectives of different farm types and the household responsibilities of men and women (Figure 6). For food insecure households, women commonly favoured increasing cowpea production over forage legumes or leucaena, as they provided the triple benefit of increasing food security, soil fertility and fodder availability, as well as income through surplus grains sales. This indicates that unless a legume technology produces grain for household consumption, women in food insecure households are unlikely to adopt it.

In comparison, even when households were food insecure, men favoured fodder over grain production. The perceived advantages of forage legumes over leaucaena were soil fertility benefits, easy forage collection, ability to intercrop and plant in wetland areas and rapid biomass production. Consequently, forage legumes managed as an annual crop suited *Livestock Focused Wetland* systems, as tree legumes can reduce rice yields – such as with *Sesbania grandiflora* in Lombok (Kana Hau *et al*. 2014). In comparison, leucaena had higher biomass production, lower weeding requirements, and could be used for fences and firewood. Consequently, leucaena was preferred in dryland systems, although if land area was limited forage legumes were preferred as leucaena planted in close proximity to food crops reduced yields.

Importantly, low levels of food security (<24% of households in ENT, FAO *et al*. (2010)) and acute labour shortages (Djoeroemana *et al*. 2007) also mean that, for the majority of households, the comparative value of forage legumes will be significantly lower than grain or tree legumes. In such circumstances, multipurpose varieties of cowpea, which produce large amounts of biomass and grain, may be a suitable option. Thus, future research should not assume homogeneity or unanimity, rather it should specifically target the key benefits and constraints identified by men and women across a range of different farm types to target the roll out of forage legumes production.

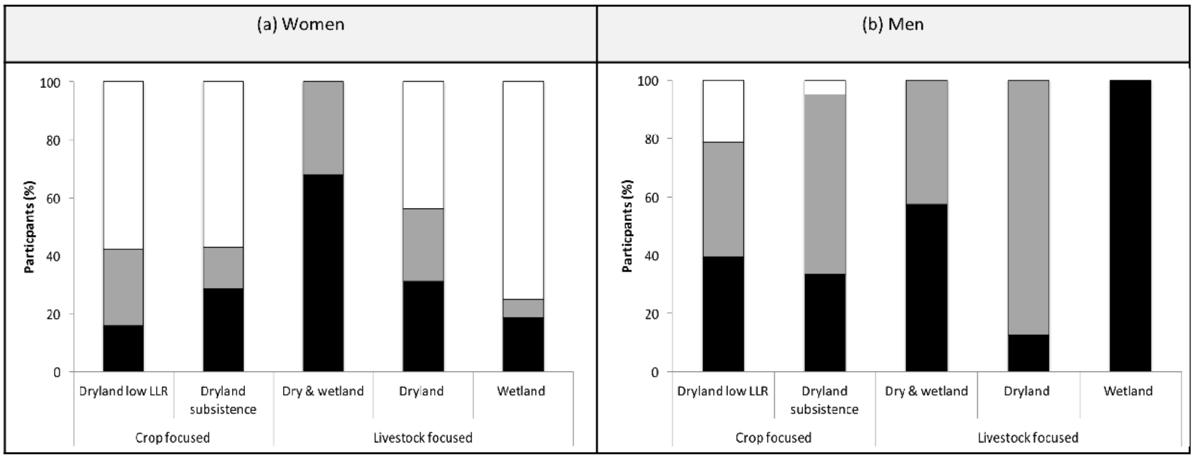


Figure 24. Preferences of legume technology options – forage legumes (black), tree legumes (grey) and grain legumes (white) – for five different farm types based on assessments of 56 female and 45 male participants from six villages in West Timor.

[A]LLR; Land:labour ratio hectares of land per adults working on the area of land available

7.5.4 Socioeconomic niche for forage legumes

This study found that forage legumes do not have universal utility, rather they are most likely to benefit food secure farmers with large resource endowments (land and labour) that are fattening and trading cattle. Thus, the 18% of farmers in ENT who own cattle (FAO *et al*. 2010) may receive economic benefits from forage legume intensification, although farmers with >2 TLU will receive the largest increase in net income. However, unequal division of labour and access and control over resources is likely to result in uneven distribution of the benefits and constraints of forage legume production. Consequently, future roll-out of forage legume will require reduction of labour inputs for women's activities (i.e. planting and weeding) and maximizing the range of benefits identified by men and women across the different farm types. This is particularly important given current adoption is more constrained by human (labour) capital rather than natural (land), physical (i.e. tools and equipment) and social (rules to prevent free grazing) capital. Despite the sound agronomic performance of forage legumes in West Timor, the current niche for forage legumes is limited, with further evidence of the labour, production and economic benefits required to achieve wider adoption.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Physiology and system benefits of tropical legumes: The project has generated novel and important fundamental understandings of the N fixation capacity and N dynamics following forage legumes. In particular, the length of time that N benefits might be expected and how forage removal greatly diminishes these effects. The project has also generated new data and information on the photoperiod and temperature effects on flowering behaviour and phenological development of tropical forage legumes which have applications outside this project; in particular in the use and development of simulation models for these species.

Simulation of tropical forage legumes: The project has also generated data that has been used to develop improved simulation models for several tropical forage legumes, which can now better estimate biomass production, leaf & stem allocations and forage quality attributes across a wider range of environments (not presented here).

Whole-farm modelling of small-holder systems: The project is also testing the use of whole-farm modelling approaches that capture labour, risk and economic returns from integrated crop-livestock systems across a wide variety of farms varying in their resources and farming enterprises. Such methodologies integrating these various components are not widely applied and have not been explored where combinations of forage development and livestock intensification are coupled in small-holder settings.

A list of scientific outputs is provided in Section 10.2.

8.2 Capacity impacts – now and in 5 years

Research capacity: We have seen a dramatic improvement in experimental management, design, data collection methods and management and presentation of research findings from collaborating researchers over the project. We have also seen dramatic increases in the confidence to engage more actively with farmers, as is evidenced by the number of farmer groups with whom our research staff are engaged. Annual project meetings provided a venue where the Indonesian and Australian team worked collaboratively on collating and analysing data, presentations and discussion of the implications of recent research findings. A range of specific skill development and on-the-job training has been provided to BPTP project staff. Specific skill development sessions have been conducted on data collection and analysis, experimental design, experimental preschedule development, delivering scientific presentations and farmer engagement approaches, using Microsoft Excel to collate, summarise and analyse data. We have continued on-the-job training in several technical areas with project staff (e.g. seed production & processing). The project also engaged 2 Indonesian Masters students from the local Nusa Cendana University and an Australian PhD student, Skye Traill (nee Gabb), in the projects research.

Next-user capacity: We have seen great improvements in the skills, knowledge and aspirations of farmers in our focus farms. For example, farmers at the Uel village group are now actively experimenting with methods for seed production in both herbaceous and tree legumes. Farmer groups have formed around the testing, development and marketing of our forage legumes, particularly related to seed production. Several farmers have also emerged as ‘champions’ of the technology, promoting forage legumes at cattle competitions/shows and amongst their broader communities.

Plate 9. Junior project scientists were involved in a range research and development skills training (left) and Dr Evert Hosang working with 'champion' farmers at Uel village to develop production of forage legume seed and biomass for livestock fattening (right).

On-farm research activities are increasingly involving regional development organisations (e.g. DINAS, BAPPEDA). These organisations have recognised a desire for and called for training to be provided that specifically focus on skill and knowledge transfer on forage legumes. Jacob Nulik and Evert Hosang have delivered several presentations at DINAS extension officer training days to improve their expertise in livestock management, forage legume cultivation and farming systems and hence their capacity to deliver better adoption outcomes to national initiatives in these areas. We packaged our information into dedicated training programs that was delivered to over 200 participants particularly targeted at increasing the capacity and knowledge of key informants in farmer networks across the region, including local DINAS and local NGO development and advisory staff, farmer group leaders and influential traders.

<u>Seed production</u>: Development of a sustainable local seed supply system is critical to the ongoing success of these forage legumes in the region. Considerable effort has focussed on assisting the Indonesian project team to develop seed production systems for the production and wider distribution of forage legume seeds including the development of locally applicable seed production, processing, storage, testing and distribution approaches. This has involved on-going training and co-development of these systems with project staff, wider training provided to other institutions including extension agencies, schools and universities.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Over the life of the project we have greatly enhanced our understanding of the scale and magnitude of economic benefits that are possible through use of forage legumes within different farming communities.

Through household modelling approaches we have demonstrated that whole-farm income can increase by up to 30% for forage legume management options which did not replace staple food crops. However, when staple crops were replaced by forages the economic impact was either small or negative and downside risk increased. Intensifying both forage legume and bull production provided a synergistic benefit, indicating that rather than feeding legumes to the whole herd, preferential allocation of legume biomass to specific classes of livestock may increase the marginal value of feed.

Notably, livestock focused farmers with enough land, labour and capacity to invest in forage legumes favoured planting larger areas of forage legumes and thus, may receive larger economic benefits. These farmers are likely to enhance farm income by up to 5 million Rp per ha of legume sown. The analysis also shows that different types of farms are likely to have different economic responses for different uses of the forage legumes. For example, land constrained farms with few cattle have greater benefits if legumes are used in relays (despite lower legume productivity), while larger and more livestock focussed farms gain greater benefits as they can use under-utilised land.

Participatory modelling indicated that management preferences and the importance of different legume benefits differed with farm type, with farmers indicating that up to 56% of maximum economic benefits are likely to be achieved on-farm. Labour constraints and other preferences influenced farmers to prefer adoption scenarios that did not maximise economic returns.

8.3.2 Social impacts

Gender focussed research on adoption drivers and limitations for forage legumes identified that their benefits are likely to be unequally distributed within the household, potentially benefiting men more than women. Women favoured using forage legumes to increase both soil fertility and fodder production and, thus, favoured planting maize-forage legume relays. In comparison, men valued fodder production and the subsequent economic benefits and, thus, favoured establishing permanent stands of forage legumes. Critically, the constraints to adoption also differed between men and women. While both men and women indicated forage legumes could reduce cut and carry labour, labour for land preparation, planting and weeding was the key constraint to adoption. Importantly, women considered these labour constraints more important than men, as women are predominantly responsible for planting and weeding crops. This indicates that a more equitable distribution of labour- or labour-saving options will be required for forage legume adoption.

Plate 10. Women involved in village participatory assessment of forage legume constraints and benefits (Photo courtesy of Skye Traill)

In several focus villages, the project activities have provided a central theme upon which farmer groups have developed and improved their group learning and confidence. With the support of the project team several groups they are now trialling their own ideas with different farmers testing different approaches to suit their needs, initiating their own purchase of livestock, developing local markets for seed and enabling them to attract other extension services to their village/community. This has seen several ‘champion’ farmers for this technology emerge who were active proponents in their networks.

We have seen an active forage legume seed trading market continue to grow. This is partially associated with promotion of leucaena in the region but with herbaceous forage legumes also benefiting. Women have been main producers of seed and hence main beneficiaries when it has been sold. In several cases, widows have benefited from selling forage legume seed to other farmers. In some cases where farmers are remote from their farm during periods of time they have subcontracted seed harvesting and cleaning to others in their community.

The ongoing involvement of SMK high schools in Soe and Aeramo (Nagekeo) has also seen forage legumes being incorporated into education programs and project staff having influential roles in guiding training of students at these schools.

8.3.3 Environmental impacts

The project has no specific targeted environmental impacts, but the integration of forage legumes into systems is likely to have some benefits for improved soil management through erosion control, increased cover and soil carbon in cropped areas and maintained soil fertility; and reduced livestock greenhouse gas emissions through improved livestock nutrition.

8.4 Communication and dissemination activities

The project has deployed a range of communication and dissemination approaches and products which targeted different next-users with our information (outlined below). Over the life of the project, the team actively involved 500 farmers and extension coordinators in dissemination and training activities (Details provided in Appendix 1).

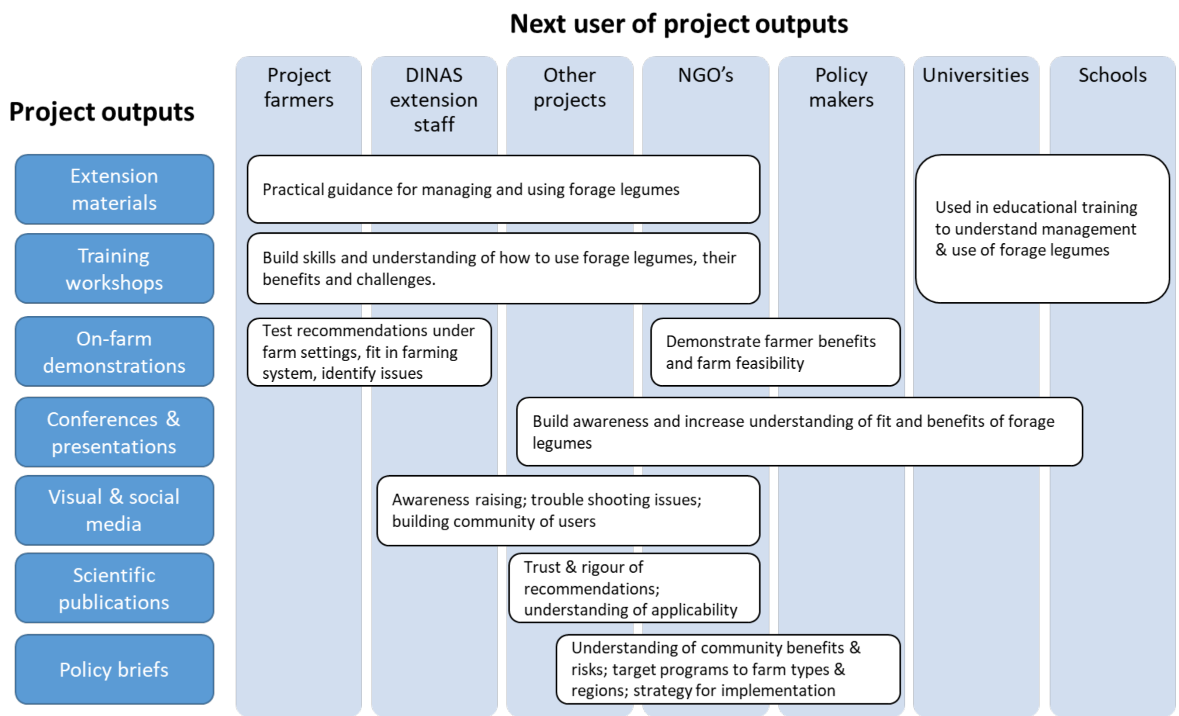
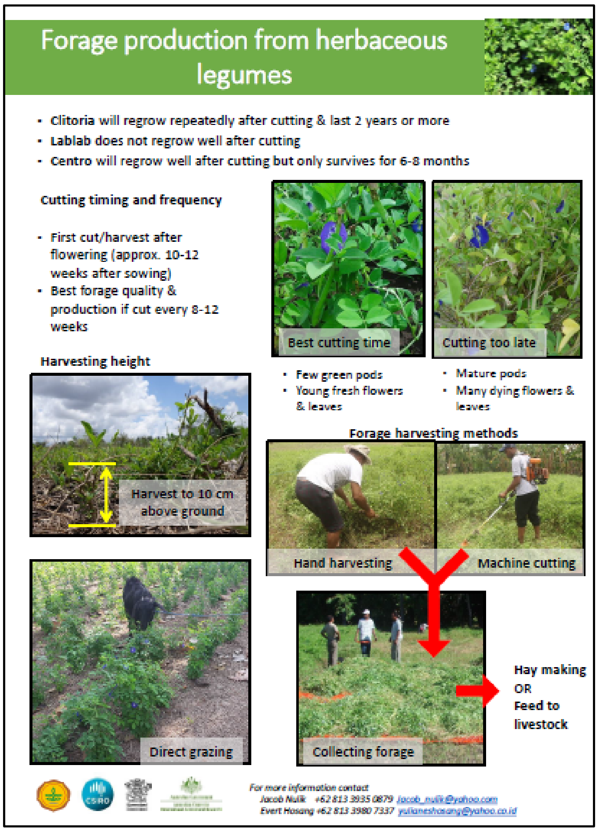


Figure 25. Summary of project communication and dissemination activities and their target audience and outcomes delivered across the project.

Extension materials: We have developed of a series of leaflets which cover the key elements of using forage legumes in farming systems in Indonesia. These materials were presented at the final project review and will be produced and contribute to training materials that have been delivered in the project and in the future. Similarly, video material has been collected and is being prepared by BPTP for publishing on the internet as a practical 'How-to' guide for using forage legumes effectively.

A series of 13 extension Fact Sheets in English and Indonesian were developed (and printed for distribution with seed, via government programs and training delivered by BPTP staff. These were designed to be a series of single page pamphlets that could be combined into a simple bound farmer-friendly guide for using forage legumes. They complement the more comprehensive book (Integrating herbaceous legumes into crop and livestock systems in eastern Indonesia, ACIAR Monograph 154) produced in the previous project. A list of the fact sheet titles is below, and 2 examples provided (in English).

1. Herbaceous legume integration on crop-livestock farms
2. Which herbaceous legumes to use
3. Integrating forage legumes with maize
4. Integrating forage legumes with rice
5. Establishing herbaceous legumes
6. Forage production from forage legumes
7. Managing pests in herbaceous legumes
8. Feeding legumes to increase liveweight gain
9. Feeding legumes to calves
10. Supplementing cows with legumes
11. Legume hay making process
12. Clitoria seed production
13. Processing and storing legume seeds



Training workshops:

The project team has developed, piloted and then delivered 12 training workshops targeting extension coordinators in local government and NGO's, leaders of farmer groups and university students; over 380 individuals have attended. These workshops have involved sessions providing general information and presentations, discussion of issues and concerns, practical demonstrations and visits to the field to observe other farmers using forage legumes.

On-farm demonstrations: The project has supported a variety of on-farm demonstrations and farmer testing of forage legumes in 11 focus villages (6 in West Timor, 2 on Sumba and 3 on Flores) with more than 120 farmers trialling forage legumes on their farms. Focus villages have been provided seed and visited every 4 weeks to provide support for implementing the forage legumes effectively. This has seen extensive evaluation of the role forage legumes could play in farming systems in ENT and identified key barriers to adoption or issues that require further research (e.g. less labour-intensive sowing techniques).

Presentations & conferences: Research findings over the first 5 years of the project were communicated to regional DINAS leaders, local NGOs and a selection of farmer group leaders at annual project meetings and in particular at the final project review meeting in Jun 18. BPTP staff have delivered many workshops/presentations to both government and farmer groups on the research findings so far.

Plate 11. Final project meeting – project junior scientists presenting research results on feeding legumes to livestock and demonstrating methods for hay making and sowing legume seeds to DINAS, NGO and BPTP extension staff.

Policy briefs and public awareness: A brief 2-page policy brief (Appendix 2) was prepared and has been provided to key decision makers in Indonesia including the head of ICARD, Dr Atien Priyanti, BPTP-ENT management, heads of livestock production and rural development departments of DINAS-ENT.

A seed production strategy was co-developed to provide information on the state of the current systems and recommend pathways for further developing seed production systems, human capacity and infrastructure to support this into the future. This was presented and provided to BPTP management and allocation of land and laboratory resources to support this is underway.

The project featured on ACIAR's Good Cooks series aimed at promoting international agricultural research and the impacts that the project has had in Eastern Indonesia to the Australian general public. This followed Debora Kana Hau on visits to villages involved in this research (and complimentary tree forages such as Leucaena) to explore the project work and how that links to cuisine in this part of Indonesia (maize, and beef).

Scientific and other publications

The team has produced numerous conference publications on various aspects of the research including both national Indonesian conferences but also international conferences. Further scientific publications are also accepted or have been drafted. These outputs demonstrate the rigour required to underpin our evidence-based recommendations.

9 Conclusions and recommendations

9.1 Conclusions

Our research has confirmed that herbaceous forage legumes can be integrated into cropping systems to improve crop yields, livestock production and livelihoods of small-holder farmers in East Nusa Tenggara, Indonesia. *Clitoria ternatea* has proven to be the most widely adapted, robust and reliable in many situations. It is a short-lived perennial that can survive for 1-3 years and can be used in a variety of ways, as an intercrop or in rotation with maize, or as permanent forage area. Farmers can easily produce and harvest their own seed.

The legumes have been found to provide multiple benefits to Indonesian farmers:

1. The capacity to increase production of higher quality forage for livestock without displacing staple food crops;

2. When grown in rotations with staple cereals crops of maize and rice, the potential to reduce fertiliser requirements and/or increase yields;

3. Increased reproduction and growth rates of cattle;

4. Reduced risk of feed shortages and capacity to support further livestock intensification;

5. Reduced labour requirements for forage collection, particularly to women;

6. Diversified income sources including options to produce seed or forage for sale even if households are not livestock producers;

7. The potential to increase household incomes by 30% or 2-8 million IDR/ha of forage grown each year. However, not all farmers will benefit equally, with those farms with livestock and limited access to non-cropping areas are most likely to gain greatest value from herbaceous legumes.

The project has significantly improved forage research, development and extension capacity in ENT, and close engagement and collaboration with several villages and government advisory agencies has seen rapid initial adoption.

9.2 Recommendations

The project has left a significant legacy of scientific outputs and materials required to support the ongoing adoption of herbaceous forage legumes in Eastern Indonesia. However, there are some aspects that may require ongoing support to see this potential reached and to maintain the momentum that has developed over the past decade.

1. Support for ongoing training of extension agents in the region, in particular to link with government livestock development programs in the region (e.g. IndoBeef). This could also capture opportunities for use of forage legumes in other parts of Indonesia (e.g. NTB). Further promotion within key central Indonesian government agencies (e.g. IARD) may also ensure the technology is continued to be promoted.
2. Regular visits to the region to monitor adoption and extension activities may be required to identify emerging constraints and develop a response to these.
3. Ongoing assistance may be required to further refine and develop the burgeoning forage seed market and potentially transition from government coordination to a private sector model.
4. There are unrealised opportunities for forage legumes to support improved beef value-chains. In particular, the provision of higher quality forages during transport

between islands to avoid weight loss and also support market incentives for animals in better condition in Eastern Indonesia.

5. The projects have had a significant impact on the development of key human resources in the region. Jacob Nulik and Debora Kana Hau have been critical to the success of forage research and extension capacity in Eastern Indonesia. There is a risk that these skills will be lost from the region upon their expected retirement in the coming years. While efforts have been made to further build capacity in forage research, no clear replacements are emerging. This may require a more active response in order to address this clear risk to ongoing support for forages as part of crop and livestock production systems in the region.
6. ACIAR should draw upon the capability developed in this project. The use of key knowledge could have significant value in other projects in tropical small-holder systems to demonstrate key approaches and information relevant in other locations.

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10.2 List of publications produced by project

10.2.1 Scientific journal articles

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10.2.4 Other papers proposed/forthcoming

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Bell LW, Hosang EY, Dalgliesh NP, Budisantoso E, Mata AD, Bria D, Rebo R, Abi Y, Traill SR. Cereal crop productivyt is increased when integrated with tropical forage legumes in semi-arid tropics of eastern Indonesia. To be submitted to *Field Crops Research*.

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11 Appendixes

11.1 Appendix 1. Record of communication, training & dissemination activities

Date	Location	Event type	Topic/content	Outcomes	Audience	Partic-ipants	Others involved
Nov 2014-May 2016	West Timor Uel, Manulai, Ekateta & Camplong villages in Kupang district Kesetnana & Oenai villages in TTS district	On-farm partici-patory evaluation	Farmers from 6 villages grew forage legumes for 2 years, producing both fodder and seed. At each village, farmers assessed the benefits and constraints of forage legumes in separate men's & women's focus groups run over an 18-month period. Farmers completed a questionnaire to assess forage legumes and characterise local farming systems. One case study per village was used for bio-economic modelling and participatory simulation evaluation.	Potential socioeconomic niche identified for forage legumes Income source from seed sales established for 1-2 farmers/village Farmers innovating to develop new ways of growing legumes (i.e. plant along fence lines)	Farmers	101	DINAS local extension officers

Date	Location	Event type	Topic/content	Outcomes	Audience	Partic-ipants	Others involved
29 February-1 March 2016	BAPPEDA Hall, Kupang District, West Timor	Training	Cattle fattening with forage legumes	Participants aware of forage legumes as a high-quality fodder	Cooperative and community groups	28	NA
3-4 March 2016	BAPPEDA Hall, TTU District, West Timor	Training	Cattle fattening with forage legumes	Participants aware of forage legumes as a high-quality fodder	Cooperative and community groups	30	NA
June 2016	Naibonat, West Timor	Training	The fodder and soil fertility benefits of butterfly pea as well as hay conservation practices	Participants understand the process and benefits for forage legume hay conservation	Undana University livestock students & SMK Highschool students	60	NA
August 2016	Philadelfia farmer group, West Timor	Training	Hay conservation and baling forage legumes	Participants know how to make forage legume hay and feed it to livestock	Farmer group members	18	NA
November 2016	Camplong 2 farmer group, West Timor	Training	Forage legumes as a cover crop and fodder	Participants understand how to use forage legumes as a ground cover and livestock feed	Farmer group members	36	FAO
81-21 – Sept 2017	Hotel Elmiya Kupang, West Timor	Training	Improved animal feeding methods using forage legumes	Understand the benefits of using forage legumes as a high-quality fodder	Extension staff and technicians from DINAS Livestock office	24	NA

Date	Location	Event type	Topic/content	Outcomes	Audience	Partic-ipants	Others involved
5-7 April 2018	BPTP Hall, Naibonat, West Timor	Workshop	Forage legume fodder production and livestock feeding practices	Participants understand the benefits of feeding forage legumes to cattle	Farmer members of a Belu cooperative	28	NA
19-12 December 2018	Hotel Olive, West Timor	Training	Production and benefits of forage legumes	Participants understand the benefits of forage legumes	Extension officers for "plant maize-harvest cattle" regional governor's program	100	NA
14-15 February 2019	BP4K Hall Kupang, West Timor	Workshop	Forage legume production on small-holder farms. Topics included forage legume livestock feeding, soil fertility benefits and seed production.	Participants developed skills to use forage legumes for fodder, soil fertility and seed production.	Extension coordinator, farmer group leader and farmers	26	DINAS Livestock Office for the Kupang District
18-19 February 2019	BPP Danga Hall, Nagakeo, Flores	Workshop	Forage legume production on small-holder rice farms.	Participants understand forage legumes can be planted after rice harvest	Extension coordinator, farmer group leader and farmers	21	NA
19-20 February 2019	BPP Kambera Lambanapu Hall, East Sumba	Workshop	Forage legume production on small-holder farms.	Farmers understand the benefits of forage legumes and how they are managed.	Extension coordinator, farmer group leader and farmers	25	NA

11.2 Appendix 2: Policy Brief

Herbaceous legumes: improving crops, cattle and incomes

Herbaceous legumes can be integrated into cropping systems to improve crop yields, livestock production and livelihoods of small-holder farmers in NTT

Herbaceous legumes provide multiple benefits to Indonesian farmers:

- Increase production of feed for livestock without displacing staple food crops
- Reduce fertiliser requirements and increase yields of maize and rice
- Increase reproduction and growth rates of cattle
- Reduce risk of feed shortages and support livestock intensification
- Reduce labour required for forage collection
- Diversify income sources
- Increase household income by 2-8 million IDR/ha forage grown/year

Why does NTT need forage legumes?

Smallholder farmers in NTT experience high levels of poverty and food insecurity.

Intensification of beef production provides an opportunity to increase incomes, but is limited by unreliable and low quality feed sources. Inadequate cattle nutrition contributes to high calf mortality rates (up to 50%), reduced reproduction, and low growth rates.

Yields of staple cereal crops (maize and rice) are low due to poor crop nutrition. Recent research has shown that integrating forage legumes into farming systems can improve nitrogen supply and yields of staple cereal crops, plus improve ruminant livestock production.

ACIAR and the Indonesian government supported research to evaluate the use of herbaceous legumes in NTT.

Herbaceous legumes

Legumes are plants which utilise atmospheric nitrogen to improve plant growth. They have a high protein content, which makes them a high quality feed for livestock.

While tree legumes such as leucaena need to be grown in non-cropped areas, herbaceous legumes can be easily integrated with current food crops. They can be grown as an intercrop or in rotation with maize, or as permanent forage area.

A range of legumes species were evaluated under local conditions in NTT:

Clitoria ternatea has proven to be the most widely adapted, robust and reliable in many situations. It is a short-lived perennial that can survive for 1-3 years. Farmers can easily produce and harvest their own seed.

Clitoria is the best herbaceous legume option for farmers in NTT

Centrosema pascuorum and **Lablab purpureus** are short lived annuals that perform well in some situations but have less reliable seed production and a narrower application.

Recommendations

- Herbaceous legumes should be promoted and supported in government strategy to increase livestock production and improve rural livelihoods in NTT.
- Training and demonstration is required to increase adoption and build capacity in extension providers.
- Ongoing support of human capacity in forage/livestock research is required to further promote legumes, respond to emerging issues, explore complementary forages, and increase seed production and distribution.

Key findings & implications

Feeding legumes can improve cattle production

Feeding legumes to Bali calves before weaning reduced mortality from 25 to 0% and doubled daily liveweight gain. Improvements in calf survival and growth rates in calves fed Clitoria were similar to those fed purchased concentrate.

Inclusion of legume in the diet of growing Ongole and Bali bulls (at least 50% of diet) increased liveweight gain by 0.3-0.4 kg/head/day.

Supplementing Ongole cows with small amounts of legume (1.5 kg dry matter/head/day) reduced loss of liveweight during the dry season and increased the likelihood of re-conceiving.

Including legumes in cropping systems can improve crop production

Legumes increase nutrient supply to subsequent crops by 25-60 kg N/ha (55-130 kg urea fertiliser). Extra N supply after legumes requires crop management (e.g. higher plant density, improved variety, fertiliser) that maximise yield benefits.

Maize yields following legumes increased by 1-2 t/ha (40-80%). Rice yields following legumes increased by 1.5 – 2.5 t/ha (50-100%).

The benefits of legumes on crop yields can last more than one year, but reduce over time.

Maize growing in rotation after legumes (left) compared to after maize (right)

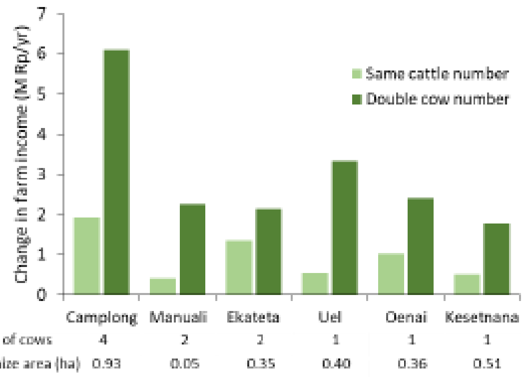
Growing herbaceous legumes can improve farmer livelihoods and income

Farms with livestock and available land will gain greatest benefits from growing herbaceous legumes (up to 8 M Rp/ha legume).

Livestock-focused farmers with limited access to non-cropping areas are most interested in using herbaceous legumes.

Growing herbaceous legumes on cropland can reduce labour required for collecting forage - benefits women and children, who are usually responsible for feeding livestock.

Large increases in farm income are possible, but replacing staple crops with forage legumes risks reducing household food security.



Predicted change in farm income from integrating forage legumes with maize either same cattle or doubling cow numbers

Farmers can produce their own legume seed

On-farm seed production of Clitoria is successful in a range of environments across NTT. Farmers can grow 500-1000 kg seed/ha/harvest (1-2 harvests/year).

Seed production can be integrated with maize and rice systems to provide additional farm income and complement forage production.

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