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# A participatory, farming systems approach to improving Bali cattle production in the smallholder crop–livestock systems of Eastern Indonesia

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A B S T R A C T

Bali cattle (*Bos javanicus*) account for about one quarter of the total cattle population in Indonesia and are particularly important in the smallholder farming enterprises of the eastern islands. The population of Bali cattle is declining in most areas of Eastern Indonesia because demand for beef cattle exceeds the local capacity to supply these animals. Indonesian agencies recognise that new strategies are required to improve the productivity of Bali cattle and to address major constraints relating to animal husbandry and nutrition. To date, the adoption of cattle improvement technologies has been historically slow in Indonesia, as is the case elsewhere.

This paper reports on key findings from a long-term study conducted between 2001 and 2009 with smallholder households from six villages in South Sulawesi and Central Lombok, to develop and test an approach for evaluating and increasing the adoption of cattle and forage improvement technologies. The approach is based on the principles of farming systems and participatory research and involved four main steps; (1) benchmarking the current farming system; (2) identifying constraints to cattle production and strategies to address them; (3) desktop modelling of the production and economic impacts of selected strategies; and (4) on-farm testing of the most promising strategies with 30 participant smallholder households.

The approach was found to be successful based on: (1) sustained adoption of a package of best-bet technologies by the 30 participating households; (2) evidence of positive production, social and economic impacts; and (3) significant diffusion of the cattle improvement technologies to other households in the project regions.



## 1. Introduction

Bali cattle (*Bos javanicus*) account for approximately 25% of the total cattle population in Indonesia. These cattle are particularly important to the smallholder farming enterprises of the eastern islands where they comprise approximately 80% of the cattle population and are an important source of capital to meet major household needs (Talib et al., 2003). The demand for beef cattle in Indonesia, both for meat and live cattle, currently exceeds the local capacity to supply these animals, with the deficit largely met by imports of beef and live cattle from Australia. Bali cattle numbers have consequently declined in most areas of Eastern Indonesia over the past decade, exacerbated by high slaughter rates for pregnant cows and a shortage of available bulls due to the sale of young bulls in response to high stock prices (Talib et al., 2003).

The Indonesian government has identified that strategies are required to significantly increase the number and quality of Bali cattle to meet the expanding demand, and to enable smallholder households to benefit from this opportunity to increase their welfare. These strategies need to address the major constraints to cattle production identified by this and other studies (Talib et al., 2003; Wirdahayati, 1994; Mastika, 2003). Typically, the most important constraint is the limited availability and quality of feed,

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especially during the dry season. Other constraints include: poor knowledge and/or capacity to implement optimum feed management practices, extended and sub-optimal breeding cycles, seasonal labour availability, animal disease, marketing constraints and limited access of smallholders to the formal credit sector for acquiring cattle and livestock handling materials.

The importance of the feed availability and quality constraint in this and other similar environments has provided the impetus for considerable investment in local (Indonesian) and international research aimed to identify cultivars for the majority of tropical environments (Ivory, 1986; Schultze-Kraft, 1986). Despite this investment and the ready availability of adapted forage species, incorporation of improved grass and legume forages into smallholder crop–livestock farming systems has been slow in Eastern Indonesia, and indeed in most developing countries (Horne and Stür, 1999). The reasons for this lack of adoption are many and varied and have been reviewed extensively by others (e.g. Shelton et al., 2005; Cramb, 2000). Nevertheless, there are some limited examples in southeast Asia where smallholders have successfully introduced forages into cropping systems (Horne and Stür, 2003; Shelton et al., 2005; Paris, 2002) and these successes demonstrate the potential benefits for smallholder crop–livestock farming systems. The cases of successful adoption were supported by a research and development approach that gave serious consideration to how the new forage options would integrate into the existing farming systems, and the impact they would have on those systems.

Previous research has shown that efforts to intensify smallholder livestock enterprises, in a component way and in isolation from the overall farming system, are unlikely to be effective (Stür et al., 2000). A characteristic feature of Eastern Indonesian smallholder farming systems is the tight integration and inter-dependency between the various biophysical elements (livestock, soils, crops and forages), resource endowments (land area and quality, feed supply, labour resources, cash availability) and social context (religion, cultural practice, risk attitudes) (Fig. 1). Additional complexity arises from the impact of temporal and spatial climate variability and interactions with the wider economy (e.g. costs and prices). As a consequence, changes to the system (e.g. management, land use) often result in complex and counter-intuitive production, economic and social impacts and understanding and analysing these impacts requires an integrated systems approach.

Simulation models have developed to capture many of the key system processes and interactions of farming systems and can be used as a tool to explore the impact, tradeoffs and viability (or otherwise) of proposed system changes. For example, Castelan-Ortega et al. (2003a,b) developed a decision support system comprised of integrated biophysical models for maize and cattle production and a socio-economic model developed to identify the optimum allocation of resources for maximising farm income. Herrero et al. (2002) developed a platform that integrates a variety of databases and component biophysical modelling tools to enable analysis of crop–livestock systems in developing countries. In this study, a novel whole farm model was developed to capture the distinctive features of Eastern Indonesian smallholder farming systems, including Bali Cattle feed responses, local feed types and management practices. The model, referred to as the Integrated Analysis Tool (IAT, McDonald et al., 2004), was used to quantify the production and economic impacts of various crop, forage and cattle improvement strategies and to identify the most promising 'best-bet' options for subsequent on-farm trialling.

Participation of smallholder households in this type of system analysis is essential to harness their intimate knowledge of how the system currently functions (including inputs and outputs). Furthermore, local participation facilitates the uptake and extension of new technologies by ensuring that the most feasible solutions are found for problems that are of priority to local households (Horne and Stür, 2003; Shelton et al., 2005). For example, the key to the successful approach adopted by Horne and Stür (2003) for forage adoption was the strong emphasis placed on smallholder participation in the whole research process, from identifying the priority issues and appropriate technologies to address those issues, to on-farm testing and subsequent extension of promising options to other households in the target villages.

This paper reports on key findings from a long-term research, development and extension program that was conducted between 2001 and 2009 to develop and test a participatory, farming systems approach for evaluating and increasing the adoption of strategies for improving Bali cattle production in the smallholder farming systems of Eastern Indonesia. The study brought together a multi-disciplinary team of research, development and extension spe-

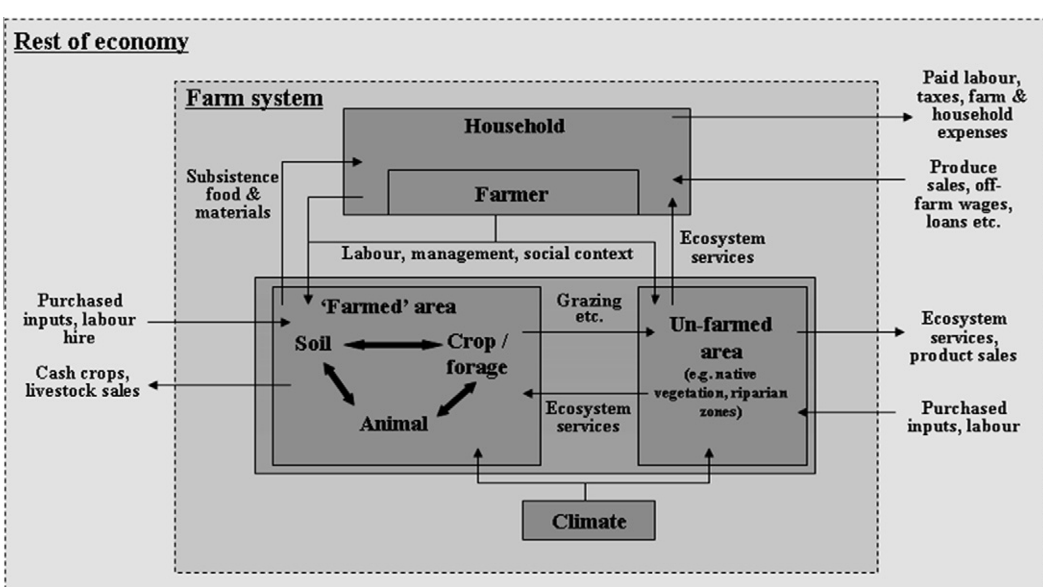


**Fig. 1.** Schematic representation of the smallholder farming system and associated resource flows (based on McCown and Parton (2006)).

cialists from a range of Australian and Indonesian agencies to work with smallholder communities in six villages in Eastern Indonesia: Lompo Tengah, Pattappa and Harapan villages in Barru Regency, South Sulawesi; Mertak village in Central Lombok Regency, Lombok and; Lemoa and Manyampa villages in Gowa Regency, South Sulawesi. The paper describes the principal steps, tools and techniques that comprised the approach and the outcomes that arose from its application across the six villages.

## 2. Description of the participatory, farming systems approach and outputs

### 2.1. Benchmarking the farming system

The first phase of the approach employed activities designed to characterise, quantify and understand the various components of the farming system and the associated interactions and exchanges between these components (Fig. 1). This information was used in several ways:

(i) To identify appropriate and representative case study villages, sub-villages and smallholder households by alignment with defined selection criteria. Selection was based on the significance of Bali cattle in the local farming systems; on-farm capacity (e.g. feed and land resource availability) and a genuine willingness by households to improve cattle production; support from community leaders and local extension agency staff; site accessibility and being representative of smallholder activities at a broader regional or Provincial scale.
(ii) To parameterise and validate the component models of the IAT (see Section 2.3).
(iii) As a baseline against which the performance of alternative forage and cattle activities and management practices could be compared and evaluated over time.

The benchmarking process commenced with the preparation of a short semi-structured questionnaire that was used to interview local community leaders. Results from these interviews, when combined with secondary data from historical village surveys, provided a broad overview of the characteristics of the local communities and farming systems which was subsequently used to guide the selection of sub-villages and to shortlist households that might participate as potential case studies. A more comprehensive household questionnaire was developed for the collection of specific farm-level data relating to resource endowments (availability of land, machinery, labour, inputs), crop and livestock enterprises (area or quantity, input requirements, management activities), farm income factors (input costs, crop and cattle prices, overhead costs, household expenses, non-farm income, credit) and constraints associated with increasing cattle production. Interviews were conducted by local project staff who were familiar with community custom and language, and who had a history of activity in the target sub-villages.

Data from the household interviews were complemented by the separate collection of primary biophysical data relating to forage availability (composition, quantity, quality), feed management (grazing, cut and carry, supplements), cattle breeding cycles (times of mating, calving and weaning), cattle performance (liveweight gain, condition score, disease, girth, height), soil characteristics (key physical and chemical attributes) and climate (long and short term records of temperature, rainfall and radiation). Forage availability and cattle performance data for each household were collected at critical times (e.g. change of seasons) over a period of 1–2 years to cover at least one complete set of seasons.

These activities were conducted over a 6–12 month period and served to build relationships between the project team, local agency staff and participating households. It allowed time for a range of formal and informal capacity building activities to be undertaken and the development of a clear understanding by all parties of project objectives, methodologies and individual roles and responsibilities.

The following summary of Eastern Indonesian smallholder farming systems is derived from these benchmarking activities.

#### 2.1.1. Key features of Eastern Indonesia smallholder farming systems

*2.1.1.1. Small, integrated and inter-dependent systems.* Smallholder crop–livestock farming enterprises are typified by small land areas (usually <2 ha) that support an integrated mix of crop, forage, livestock and human activities. In common with smallholder systems in much of Asia, Africa and the Pacific, these enterprises involve linkages between the 'farm' and 'household' activities (Fig. 1) that are generally acknowledged to be stronger and more mutually dependent than for western farming systems (Ruthenberg, 1980, Norton et al., 2006). For example, household labour is potentially used on-farm (e.g. ploughing, weeding, harvesting, herding etc.), on neighbouring farms (e.g. similar farming activities for cash or reciprocal services), and in non-farming roles (e.g. operating a kiosk, construction, transport services). Some crop and animal activities produce intermediate outputs that are inputs to other activities (e.g. cattle provide crop nutrition inputs through manure and draught power for cultivation). Because the products from these smallholder systems seldom have alternative markets in which they can be traded, opportunity valuations are given far less prominence in decision-making than may be the case in agricultural systems in more developed countries. Importantly, because activities are typically inter-linked, commitments to new activities may either increase or reduce production and consumption opportunities elsewhere with consequences for household welfare.

*2.1.1.2. Seasonal climate.* While there is substantial spatial and inter-seasonal variability in the timing and extent of rainfall across Eastern Indonesia, the 'rainy season' typically commences in November–December and ends in April–May, followed by an essentially rain-free 'dry season' for the remainder of the year.

*2.1.1.3. Land use.* While smallholder farms may be comprised of many small parcels of land, these are commonly represented by two basic land types. 'Cropland' is typically located close to the main residence and is used for cultivating a range of annual crops. This land is usually naturally flat or formed into terraces, has deeper and more fertile soils, with access to simple irrigation or is bunded to retain overland flow. Essential food crops, such as rice and maize are grown during the wet season. The length of the wet season and access to irrigation determines the selection, extent and number of crop cycles in 1 year. Other important food crops that are grown in cropland areas include peanut, sweet potato, soybean, mungbean, cassava and tobacco. 'Upland' is typically located further away from the house, is larger in area, and is usually less accessible. This land often includes sloping ground with shallow and less fertile soils and no access to irrigation; and is used to grow perennial fruit (e.g. mango, coconut, cashew), fibre (e.g. kapok) and timber crops (e.g. teak, bamboo). Upland areas are often important areas for the production of native and introduced perennial and annual forages, and are also important areas for grazing cattle. Many of the forage species that are grown in the upland areas are also grown along cropland bunds or around the perimeter of cropland as 'living fences'. For a variety of cultural and logistical reasons, upland areas are commonly shared by more than one household and grazing of this land is often communal; whereas cropland is typically used exclusively by the household owners, although communal grazing of crop residues does occur in some locations.

*2.1.1.4. Forage production and feed management.* Depending on the time of year, cattle either free graze crop stubble, 'native' pasture or forages, are tether grazed, or are penned and hand-fed various mixtures of 'cut and carry' forage. Maximum rates of forage production occur during the wet season, and decline to almost zero at the end of the dry season. Hence, during the wet season when feed is plentiful, households allow their cattle to free graze in the upland or tether graze closer to the house to avoid damage to the field crops. This pattern continues for a period beyond the rainy season with the grazing of 'pasture' supplemented by crop residues and stubble post-harvest. As the dry season continues, more accessible feed sources are gradually depleted and households are required to commit increasingly more labour to procure feed for their cattle, either manually gathering feed if the stock are penned or tethered, or moving their cattle more often and further away from the house when grazed. The quality of available feed declines significantly as the dry season progresses with greater dependence on less palatable, less digestible and low-protein feed. Households attempt to address the shortfall in the quantity and quality of available feed at this time of year through the use of tree leaves, banana leaves and stem, cashew apple or, in limited cases perennial legumes such as *Gliricidia spp*, *Leucaena spp* and *Sesbania spp*, or conserved crop residues.

*2.1.1.5. Livestock production.* Bali cattle play a central and multi-functional role in these smallholder farming systems including: (1) draft animals for field operations such as tillage; (2) a readily saleable store of capital to meet major household needs (e.g. school fees, house repairs and electronic equipment, religious travel); (3) a means of accumulating wealth and status; and (4) as a business enterprise to generate income (Padjung and Natsir, 2005). Traditionally, the latter role has been rarely employed. In addition to Bali cattle, households keep a variety of other types of livestock, including buffaloes, goats, ducks, chickens and geese for the provision of draught, meat and other animal products for home consumption or limited sales. Mating of Bali cattle commonly occurs late in the dry season to early in the rainy season with calving during the following dry season. A lengthy weaning period follows where the cow's milk is supplemented with 'cut and carry' material. The lactation period coincides with the dry season when feed of high quality is in short supply. Once the rainy season commences, the existing labour use is prioritised to field preparation and planting of rice or maize. Consequently, cutting and carrying of forages to supplement tethered or housed animals is of relatively low priority for households. Furthermore, the mating cycle often leads to an overlap between lactation and draught activities early in the wet season when the fields are being ploughed in preparation for rice planting. It is not unusual early in the rainy season to see cows ploughing the field while being followed by milking calves. Additional stress can occur about this time of year when the diet changes from primarily dry forage to green forage as the wet season takes hold. This cycle leads to declines in the condition of lactating cows, calf growth rates and the reproductive ability of cows.

*2.1.1.6. Family structure and labour profile.* The smallholder household structure tends to be multi-generational (often comprising three generations) with all household members contributing to a varying extent to the management and operation of farm, non-farm and household activities. Key farm activities include: land preparation; sowing and transplanting the crop; fertilising; chemical application; weeding; harvesting, threshing, bagging and transportation of the harvested product; cattle tending; forage gathering; and water gathering. Additional labour is often hired to assist with harvesting and land preparation activities; while supplementary income may be sought from off-farm activities that are both agricultural (e.g. harvesting) or non-agricultural in nature (e.g. construction, kiosk).

### *2.2. Identify constraints to cattle production and strategies to address them*

A series of meetings were held in each village at which the benchmarking results were discussed with the participating smallholders to ensure their validity. Small group discussions followed in which the participating households were asked to discuss further the constraints to cattle production and to nominate potential strategies to address those constraints.

There was strong uniformity across the project study regions regarding the perceived constraints to increasing cattle production including feed quality and quantity, stock water availability during the dry season, insufficient capital to increase herd size, labour constraints for collecting feed, market shortcomings (e.g. cattle price differential between trader and farmer), disease, inadequate knowledge of optimum feed management, poor cattle housing, access to bulls for mating and sub-optimal breeding cycles. These constraints can be grouped into three categories.

The first category includes market and capital access constraints which are difficult for the household to directly influence (at least in the short term) but may be overcome indirectly with time through the production of higher quality cattle (achieved via other cattle improvement strategies). Households typically do not have the cash reserves or access to loans to enable them to buy a bull or more cows for breeding. Hence, they must build up their herd independently. However, this is often difficult as households need to sell cattle to release cash for other household expenses.

The second category is comprised of constraints that can be addressed through simple strategies, many of which are available to smallholders but are often not accessed and for which the impacts are readily apparent. For example, disease is typically minor and sporadic in extent and adequately controlled by a vaccination program run by the local extension agency (Dinas Peternakan). Bull access can be addressed through the promotion of bull retention by households and the provision of fee-for-service mating to other households. The provision of adequate stock water can be addressed through simple low-cost technologies such as rooftop rainwater capture and storage in wells or covered pits, dam construction, and the recycling of household grey water into drinking troughs.

The third category includes constraints associated with feed quality and quantity, feed management and the breeding cycle, for which solutions are more difficult to specify and implement, and the broader implications are often more complex. Analysing these impacts is likely to benefit from a systems-level approach in which scientists, farmers and extensionists work together in order to identify and design strategies that are both feasible and viable for the smallholder.

The study focussed primarily on addressing the third group of constraints through the following strategies identified during the farmer workshop discussions:

#### *2.2.1. Improved use and management of existing forage and crop species*

Many existing forage species are of high quality but are poorly utilised and managed. For example, tree legumes such as gliricidia (*Gliricidia sepium*) and leucaena (*Leucaena leucocephala*) are excellent sources of high quality dry season feed but are not widely used due to local perceptions of poor palatability. Similarly, elephant grass (*Pennisetum purpureum*), while of poor quality, is popular in most regions due to its fast growth rate and persistence into the dry season. However, the management of elephant grass is often poor (i.e. cut too hard and too often, or allowed to grow tall and rank, no use of fertiliser). To address this issue, optimum cultural practices for key species were collated from pre-existing sources and provided to the households through on-farm demonstration, fact sheets and other extension methods.

*2.2.2. Introduction of new, improved forage species*

To address specific shortfalls in feed quality and quantity across the six village environments, a total of 10 grass and seven herbaceous legume species were introduced. Species selection was largely based largely on pre-existing information (Peters, 2005) and took into account adaptation to the soil and climate conditions of Eastern Indonesia and suitability for cultivation in a variety of locations and arrangements including: mixed forage banks in either lowland, upland or backyard areas; along bunds bordering lowland fields; after annual crops (i.e. as part of the crop rotation); or as an understorey to upland estate crops. Seed and cutting material were obtained from local and Australian sources and multiplied at both on- and off-farm sites. Seed was provided to best-bet households along with cultural advice for each type.

*2.2.3. Better use and improvement of crop residues*

Feed quality and quantity constraints can also be addressed through enhanced utilisation of existing crop residues. Following removal of the grain or harvested product, the residue can be fed either directly to cattle or dried, bagged and stored under cover for use as a supplement during critical feed shortage periods. The most suitable sources are higher quality leguminous crops such as peanut, cowpea and mungbean.

*2.2.4. Earlier calving and weaning*

The adverse effects associated with uncontrolled mating, dry season calving and delayed weaning described in Section 2.1.1.5 can be lessened by adjusting the mating time so that calving occurs toward the end of the rainy season when feed of reasonable quality is still available and the breeding cow is in good condition. Re-mating can take place three months later to establish a 12 month calving cycle (currently 16–18 months) and to increase calving rates. Furthermore, with this schedule, the cow is being used for draught at a safe time of the pregnancy and is not raising a calf at the same time. Households were encouraged to wean their calves at a younger age (~6 months) and to preferentially feed thereafter. This is known from the work of Quigley et al. (2009) to maximise calf growth rates and to reduce the stress on the cow, especially during the dry season.

## 2.3. Desktop modelling of production and economic impacts of selected strategies

The *Integrated Analysis Tool* (IAT, McDonald et al., 2004) was used to analyse the resource use, production and financial impacts of strategies 2.2.1–2.1.4 and their sensitivity to village climate, soil, management and farm design variables. The IAT was initially configured to represent current management and performance of a generic, 'representative' farm in each village, using data and information from the village benchmarking activity. The model output for this 'baseline scenario' was presented to households at the village workshops for validation purposes and, once model performance was satisfactory, the alternative strategies were then analysed via a series of stepwise adjustments to the baseline scenario. Using the model in this way enabled the households to see the potential impacts and tradeoffs of these strategies on forage, crop and cattle production, labour usage and availability, forage supply and finances. This virtual testing of strategies was used to identify a list of viable and feasible best-bet options for subsequent on-farm testing (Section 2.4).

*2.3.1. Integrated Analysis Tool (IAT)*

The IAT is a whole farm model that captures the key economic and biophysical processes, and their interactions in the smallholder farming system. It integrates three separate models: a pre-existing farming system model (APSIM), and new models for predicting Bali cattle growth and mimicking the economic performance of a typical smallholder farm-household (Fig. 2). A user-friendly interface forms the 'hub' of the IAT with links to other input forms.

*2.3.1.1. APSIM.* The *Agricultural Production Systems Simulator* model (APSIM) simulates the growth of a wide range of crops in response to site-specific soil, climate and management data (Keating et al., 2003). Simulation modules representing different elements of the farming system are integrated to represent the system of interest. In this case, crop modules for rice (Bouman et al., 2001), peanut (Robertson et al., 2001a), mucuna (Robertson et al., 2001b), cowpea (Adiku et al., 1993), maize (Carberry and Abrecht, 1991), stylosanthes, soybean (Robertson and Carberry, 1998) and mungbean (Robertson et al., 2001a) were combined with the soil water module SOILWAT 2 (Probert et al., 1997), the soil nitrogen and carbon module SOILN2 (Probert et al., 1997) and the residue module SurfaceOM (Probert et al., 1997). Pre-run APSIM output relating to forage and crop yield and quality for these crops was added to a database within the IAT to enable integration with the other component models.

*2.3.1.2. Bali cattle growth model.* While there are many published models for predicting liveweight gain of cattle, none are appropriate for many of the feedstuffs commonly used by Indonesian smallholders or could be confidently applied to Bali cattle, which are small in comparison to European breeds with estimates of mature weight of females ranging from 250–350 kg/head and males up to 450 kg/head (Devendra et al., 1973; McCool, 1992; Sukarini et al., 2000). A Bali cattle production model was developed that combines published secondary data and field data from project activities relating to animal liveweight, liveweight gain, milk production, age at first calf and calving interval, as well as the quality, composition and quantity of the various sources of feed. The model is principally based on the energy functions outlined by SCA (1990) with coefficients recalibrated for Bali cattle, but includes intake restrictions based on estimated crude protein requirements of Bali cattle (Poppi et al., 1999). Data input is restricted to protein concentration (g/kg) and dry matter digestibility (%) of the forage, with annual pasture and forage residue biomass, nitrogen content and

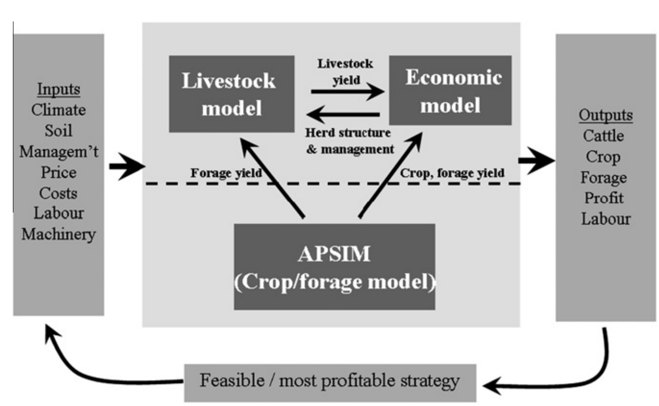


**Fig. 2.** Structure of Integrated Analysis Tool (IAT).

date of harvest sourced from the database of APSIM output. The digestibility and calculated intake determines the digestible and metabolisable energy intake which is partitioned into energy for maintenance, growth and lactation. The animal growth rates predicted by the model are in reasonable agreement with observed values (Fig. 3).

Calving interval, age at first calf and calf mortality rates are related to the condition of cows, based on the survey data of Wirdahayati (1994) and field observations. The derived functions indicate that a 200 kg animal will have its first calf at around 30–36 months of age, and a cow needs to be approximately 260 kg to have a calf at 12-monthly intervals. Labour requirements for cut and carry of necessary forage are varied according to forage availability. The greater the shortage of forage, the greater the labour requirement as smallholders need to collect forage from greater distances or spend time herding animals on common land.

*2.3.1.3. Smallholder enterprise economic model.* Consistent with the inter-linked 'farm' and 'household' input and output dependencies illustrated in Fig. 1, the economic model is constructed around a wide array of activities that may be undertaken by the household. These include crop, forage, livestock, off-farm and non-farm activities that are linked systemically through four resource pools that the activities can either draw on or contribute to: (a) labour including both household members and access to additional casual labour – by functional category and season, (b) land by type and quality, (c) forage by type and seasonal availability, including crop residues, and (d) cash reserves and credit – i.e. working capital to support production and consumption activities. By including all of the activities that are available to, or necessary for, the household to meet its needs and objectives, the model is able to provide an accurate guide to whether exploiting different crop and forage options will actually make the household better or worse off.

Inputs to the household model are drawn from several sources. Yield data for crop, forage and livestock activities are sourced directly from the APSIM database and the livestock model. Price and cost data, production input levels (e.g. fertiliser, seed, materials), and home consumption needs of different products and family expenses are derived from the benchmarking survey of households located in each of the communities with which the project was working.

The main economic measures that are produced by the model include: (a) total gross margin – including value of home consumed produce, (b) disposable income after household consumption, (c) net cash balances, and (d) the level of accumulated household capital and any outstanding debt balances. These measures are calculated by placing prices on produce outputs and production inputs along with 'opportunity values' for home consumption and other non-market uses or disposals of activity outputs (e.g. food crops, residues, manures etc.). Rather than employing an automated optimization strategy, a creep budgeting approach was selected which involves re-specifying various input and output variables in a systematic manner to explore the system response to these changes (Makeham and Malcolm, 1981). That is, the decision-maker 'creeps' around the economic response surface in a systematic fashion to examine whether there is a shift towards or away from a more optimal solution. In this way, the use of 'what-if' questions provides smallholders, researchers and extension specialists with important insights into how the economic position of the farm-household system will respond to different activities.

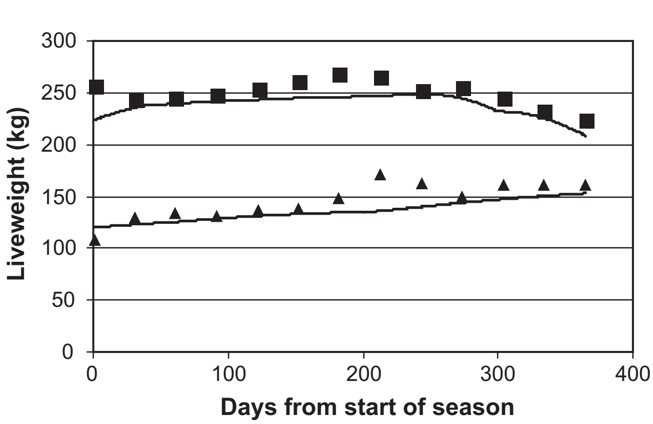


**Fig. 3.** Predicted (lines) and observed (points) liveweight of Bali cattle for two different commencing ages.

*2.3.1.4. Example application of the IAT.* An application of the IAT is illustrated using an example drawn from Kading sub-village, Barru Regency, South Sulawesi (Latitude −4.5°S, Longitude 120.0°E, average annual rainfall 2890 mm) which explores the prospective impact of a range of livestock improvement strategies. The results are summarised in Table 1. Based upon the benchmarking data collected in the village, a typical 'representative' smallholder farm was configured within the IAT that is comprised of 0.54 ha of non-irrigated rice on lowland during the wet season, 0.3 ha of peanut on upland during the wet season and a maximum of two cows. Some 80% of the peanut residue is conserved each year for cattle feed and 30 kg of cut and carry forage is also collected per day. The family is comprised of two adults and two children. The male adult presently works 255 days per year, the adult female 105 days per year and each child is available to help with farm activities for up to 45 days per year. Household consumption of rice and peanut is 184 kg and 30 kg per annum, respectively by adults, and for children the annual consumption rate is half of that amount. While surplus grain is sold for cash, the primary source of cash is from the sale of cattle as weaners at a price of Rp14,000/kg (at the time of writing USD$1 = Rp12,035). Under this baseline production system, the IAT predicts a substantial fodder deficit which will need to be met by the collection of feed off-farm. It also predicts that there would be insufficient labour resources available from within the household to conduct these activities, and that the household members would either need to work longer hours or recruit labour services from elsewhere.

The smallholder workshops nominated four options for improving livestock production for Kading sub-village which were subsequently investigated with the IAT (Table 1). Each of these options, presented as Scenarios, represents a progressive step from the previous one and the projected results are cumulative.

*2.3.1.5. Scenario 1. Increasing the conservation and quality of crop residues.* The retention and subsequent fermentation of 40% of the rice straw produced on the farm lowered the annual fodder deficit, and increased cattle sales by one animal and the cash balance from Rp 14 million to Rp 22 million over a 5 year period (Table 1).

*2.3.1.6. Scenario 2. Increasing the area of existing planted forages.* The establishment of a 200 m row (living fence) of gliricidia plus 0.3 ha of elephant grass in the upland replaced the fodder deficit with a substantial surplus and increased cattle sales by two additional animals over 5 years resulting in an increase in the cumulative cash balance of Rp 9 million. The ready access to these new feed sources acted to relieve the labour deficit.

*2.3.1.7. Scenario 3. Increasing the number of cows and the daily amount of cut and carry.* Increasing the cut and carry rate from 30 to 50 kg/day and the number of cows from two to four exhausted

**Table 1**
Results from IAT application at Kading sub-village, South Sulawesi. Negative values indicate a deficit.

| % Crop residue retention | Cut and carry (kg/day) | Cattle sold over 5 years | Fodder (kg/year) | Labour balance | 5 Year cash balance Rp million |
|---|---|---|---|---|---|
| *Baseline: wet season: 0.54 ha lowland rice, 0.3 ha upland peanut, 2 cows* | | | | | |
| 80 peanut | 30 | 6 | −3000 | Deficit | 14 |
| *Scenario 1: baseline + fermented 40% of rice straw* | | | | | |
| 80 peanut | 30 | 7 | −2000 | Deficit | 22 |
| *Scenario 2: Scenario 1 + 200 m of tree legumes + 0.3 ha elephant grass* | | | | | |
| 80 peanut | 30 | 8 | +4000 | Adequate | 23 |
| *Scenario 3: Scenario 2 + 2 extra cows + increased cut and carry* | | | | | |
| 80 peanut | 50 | 14 | 0 | Adequate | 38 |
| *Scenario 4: Scenario 3 + seasonal mating* | | | | | |
| 80 peanut | 50 | 17 | −2000 | Adequate | 43 |
| *Scenario 5: Scenario 4 + 20% reduction in cattle sale price* | | | | | |
| 80 peanut | 50 | 17 | −2000 | Adequate | 35 |

all of the fodder surplus, increased cattle sales by six animals and the cash balance by Rp 15 million over 5 years.

*2.3.1.8. Scenario 4. Introduction of seasonal mating.* This involved shifting to a 12-month breeding cycle to better synchronise feed availability to the needs of the cow and calf in order to improve animal growth rate and faster turnaround times from birth to sale. This strategy increased total cattle sales by three animals and the cumulative cash balance by Rp 5 million over 5 years, but in the process created an on-farm fodder deficit that has to be resolved by seeking fodder from alternative sources.

*2.3.1.9. Scenario 5. Sensitivity to reduction in cattle prices.* The effect of a 20% decline in the price of Bali cattle would be to reduce the 5 year accumulated cash balance for Scenario 4 from Rp 43 million to Rp 35 million. This outcome, however, would still represent a considerable improvement over the original baseline scenario.

### *2.4. On-farm testing of best-bet strategies*

The major outcome of the household workshops conducted in each village was a list of strategies, agreed by the smallholders as potentially feasible from resource supply and social perspectives, and which were shown by the IAT model to prospectively improve cattle production and the economic welfare of the household, without undue impact on other aspects of farm activities (e.g. labour, cropping). The next step was to test these options on-farm. A total of 30 households (referred to as ‘best-bet’ households), were selected from each of the six villages to trial these strategies on their own land. These trials were conducted for at least 2 years and provided an opportunity for the participant households to experience and evaluate the best-bet strategies in the context of their own land and to demonstrate and communicate project findings and methods to other households (i.e. an extension ‘platform’). A package of best-bet activities (selected from the list arising from the earlier workshop) was tailored for each best-bet household taking into account the environment and resources of each farm and the individual circumstances and preferences of the households. The package included farm-specific versions of the four strategies outlined in Section 2.2 as well as additional limited assistance where appropriate to address other constraints such as bull and stock water access. In return for technical advice on these strategies and the provision of consumables such as seed, cuttings and fencing material, the households agreed to provide land and labour for testing purposes.

Impacts on forage availability and cattle performance arising from the on-farm trials were monitored using the same techniques adopted during the benchmarking activities. In addition, comprehensive interviews were conducted with each best-bet household at the end of the project (February 2008) and 20 months after the completion of the project (October 2009) to assess the impact and retention of the best-bet strategies. These interviews captured qualitative and quantitative information relating to the impact of the project on farmer practice and management, land use, household finances, labour usage, cattle production, forage and crop production, non- and off-farm activities and future intentions. The interviews were conducted on-farm by a small team of Indonesian and Australian project team-members.

## 3. Impact evaluation

### *3.1. Uptake of best-bet strategies*

At the commencement of the on-farm trials a total of 157 individual best-bet activities were identified across the 30 best-bet households. By the end of the project (February 2008), 117 of these activities were ‘active’, increasing to 157 by October 2009. These activities are summarised in Table 2. For many of the best-bet households, the list of activities identified as having been undertaken at the end of the project differed to some extent from the initial farm specific recommendations. The households were influenced and motivated not only by the actions of the project team but by interactions with other households (via field days and less formal interactions) and the legacy of previous ACIAR (Australian Centre for International Agricultural Research) projects. Hence, while most households have adopted the initial best-bet strategies, there were some deviations over the course of the project. At the second round of interviews in October 2009, all of the households confirmed they would continue to practice the best-bet strategies that had been implemented.

### *3.2. Forage production*

At the start of project, the best-bet households had on average less then 0.03 ha of improved herbaceous forages, with most of that comprising small forage banks of elephant grass in the Barru villages of Lompo Tengah and Harapan. The Lemoa, Manyampa and Mertak households had very little, if any, improved forage banks. By February 2008, the average across all sites was approximately 0.11 ha with the greatest increases being in the Barru Regency villages which had better rainfall and a longer history of contact. By October 2009, this had risen to an average of almost 0.4 ha, which represents a substantial improvement in quality fresh forage supply across all study villages. In some cases forage production has expanded into new land areas not previously pro-

**Table 2**
Summary of the range of options trialled by participating 'best-bet' households under the four main categories.

| | |
|---|---|
| New herbaceous forage introductions | New grasses and forage legumes for lowland, upland and backyard use as forage banks, bund plantings and dual pasture/cut and carry forage sources |
| Better use of existing fresh forages | Better management and use of elephant grass<br>Increased tree legume use (i.e. *Gliricidia, Leucaena, Sesbania*)<br>Improved upland grazing management |
| Better use of conserved forages | Conserved rice straw – rice straw ammoniation<br>Conserved crop legumes (e.g. peanut, soybean, mungbean straw)<br>Other crop and forage conservation (e.g. maize stover, forages for hay) |
| Cattle breeding, feeding and management | Controlled mating<br>Early weaning<br>Preferential feeding of young cattle or cows and calves<br>Supplement feeding (i.e. rice bran)<br>Better cattle housing and feeding systems (i.e. backyard kandangs)<br>Stock water supply improvements (i.e. grey water, rooftop capture) and dam construction[a] |

[a] These activities were undertaken at the households own initiative but after experience with project.

ducing forages, while some households had purchased or leased additional land to grow forages.

Tree legume resources and use also increased significantly over the same period, with the average gliricidia row length increasing from under 10 m at the start of the project to over 120 m by October 2009, with the biggest increases being in Lompo Tengah, Lemoa and Mertak. Gliricidia is now used throughout the year, especially during the dry months when nearly 100% of households with cattle now regularly feed gliricidia (Fig. 4). Previously, tree legume was underutilised in this village and hence readily available to those who were accessing the local supplies, whereas now it is actively sought by most households during the dry season as an important source of quality feed. Mertak households have also expanded sesbania plantings significantly in the last 2 years.

### 3.3. Cattle production

In the October 2009 interviews, 90% and 97% of best-bet households, respectively, believed the cattle growth rate and condition of their cattle had improved in response to the improved feed and cattle management practices. Some 60% of households attributed sale price gains at least in part to improved animal condition and quality. However there was considerable uncertainty about the impact of cattle improvement strategies on price due to the confounding influence of general increases in market demand and prices since the commencement of the study. Similarly, average farm cattle holdings and sales have not changed significantly since the study commenced, attributed primarily to cattle holdings typically fluctuating substantially for a range of reasons often unconnected with forage supply, cattle condition or price. It is not unusual for all or most of a household's cattle to be sold in order to generate cash for a one-off significant expense (e.g. wedding, house construction) and it may take many years to rebuild stock numbers back to previous levels. Nevertheless there are case-specific examples of where these indices have increased significantly.

#### 3.3.1. Case 1. Jufri household, Lompo Tengah, Barru, South Sulawesi

Over the course of the study, this household established a 1 ha bank of mixed forages (*Pennisetum purpureum*, *Clitoria ternatea*, *Setaria sphacelata*, *Gliricidia sepium* and *Paspalum atratum*) plus a further 300 m planting of gliricidia tree legume. Cattle production has shifted from a free and tethered grazing feeding system to a stalled system (i.e. kandang), with cattle fed on cut and carry feed collected from the expanded on-farm forage sources. The household has also invested in a bull to enable controlled mating and is practising early weaning and preferential feeding. In response to these changes, the cattle holdings have increased from five head at the commencement of the study to 15 head by October 2009. Forage and cattle monitoring activities confirmed that the forage bank provided up to 40% of fresh forage requirements for three yearling male cattle for most of 2006 and resulted in improved growth rates of 0.30 kg/hd/day, twice the rate of the Lompo Tengah average of 0.14 kg/hd/day (Fig. 5).

#### 3.3.2. Case 2. La Matta household, Harapan, Barru, South Sulawesi

The La Matta household has more than quadrupled the forage production area (from 0.1 ha to 0.45 ha), introduced a range of

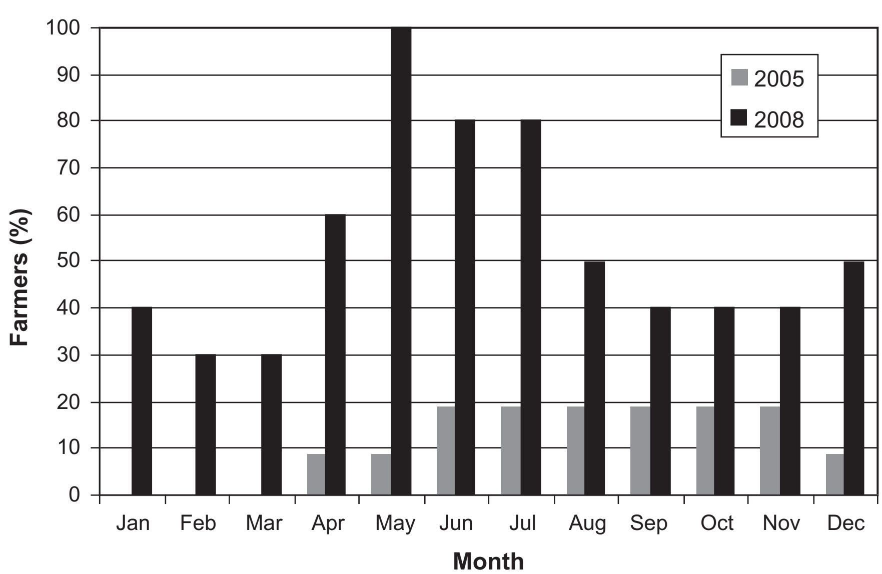


**Fig. 4.** Percentage of best-bet households using *Gliricidia sepium* for cut and carry forage in 2005 and 2007 at Mertak, Lombok.

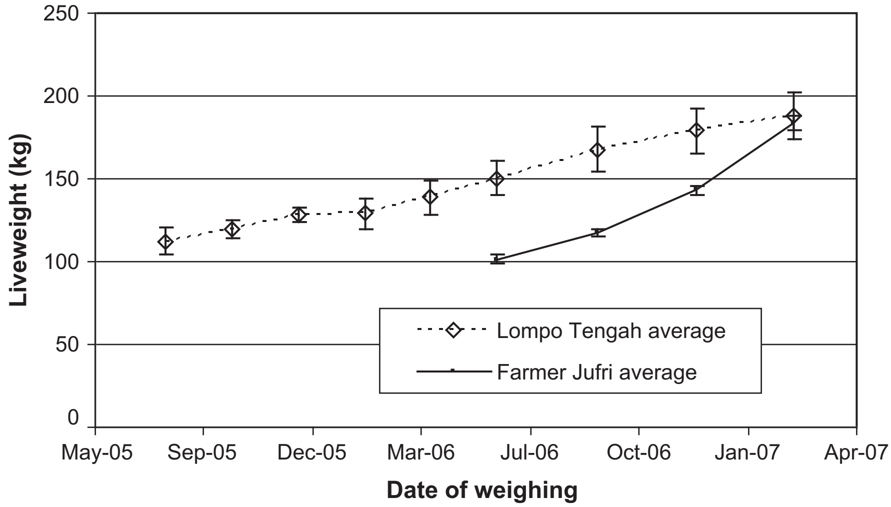


**Fig. 5.** Comparison between growth rates of the farmer Jufri households' yearling male cattle fed from an established forage bank and average growth rates for similar young male Bali cattle at Lompo Tengah during 2006–2007.

new and improved forage species, expanded gliricidia production from 10 m to 30 m and commenced improved forage management practices (e.g. fertiliser, optimum elephant grass cutting practices). Similar to the Jufri household, cattle production has shifted away from a grazing-based system to one based on kandangs and cut and carry feed. Early weaning and preferential feeding of calves is also being practiced. Over the course of the study the household has increased its cattle ownership from two head to four head. Monitoring of the cattle from 2005 to 2007 showed the liveweight gain of the cows and young males exceeded the average gains across the other non best-bet households within the village. This is attributed to the combined effect of new forage banks, better management of existing elephant grass to maximise leaf production and improved feeding management (Fig. 6).

### 3.4. Household labour

In the October 2009 interviews, 80% of best-bet households reported savings in on-farm labour used for both forage and cattle management, with the remaining households either uncertain as to the impact or not reporting a change. Estimates for time saved were highest in Mertak, ranging from 3 to 6.5 h in the dry season compared with approximately 2–3 h per day in the other villages. This saving is attributed to increased and more accessible on-farm forage production, especially of more dry-season persistent species such as gliricidia. Mertak is a particularly dry location, for which it was a common and expensive practice to hire small trucks to collect crop residues from other regions several times during the dry season, was previously a common and expensive practice. For most of the Mertak best-bet households (seven out of nine), this activity has now been largely replaced with feed sourced on-farm displacing up to six truckloads of feed per annum and representing substantial savings in both labour and cash. This of course will be a season-by-season proposition with off-farm feed still likely to be required in poor seasons.

Freed-up labour has been reallocated to miscellaneous crop management tasks (e.g. weeding and in some cases, an expansion of the cropping area), rest, non-farm or off-farm employment activities or intensification of forage and cattle management.

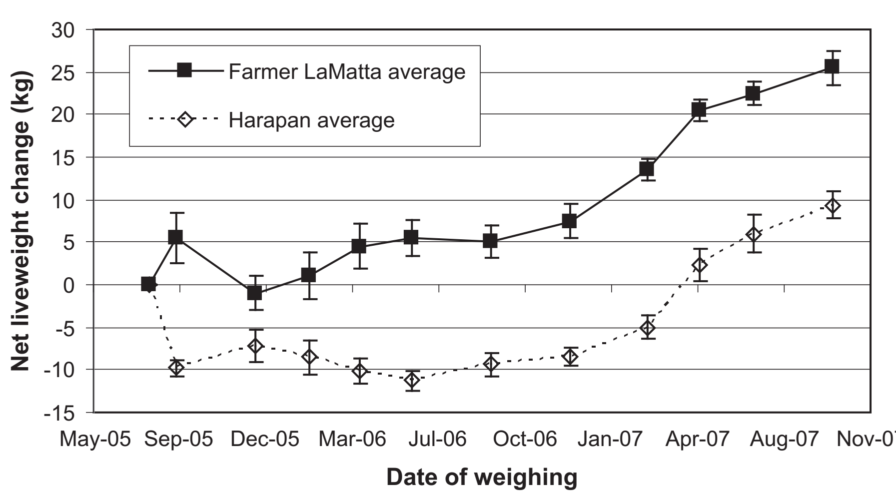


**Fig. 6.** Net liveweight change comparison August 2005 to August 2007 between farmer La Matta's cows and the average across the other non best-bet households at Harapan, Sulsel.

### 3.5. Household income

More than half (53%) of the best-bet households interviewed in October 2009, reported gains in household income over the course of the study. Of the remainder, one household reported no change and the rest were uncertain with no household actually reporting a decline in income. Attributing these changes specifically to the adoption of best-bet strategies and the resultant impact on cattle price or sale number requires caution due to the erratic nature of cattle sales coupled with the confounding effects of the general rise in cattle prices in response to ever growing demand. Even where cattle production has clearly increased and trader interest has grown, most households remain price takers rather than price makers as they sell cattle only when they need cash, rather than as a source of regular income. Nevertheless, many best-bet households report traders actively seeking their cattle as they are in better condition than other cattle in their village or neighbouring villages.

### 3.6. Diffusion of technologies to other smallholder households

Beyond a major role in trialling and refining their best-bet practices, each one of the participating households represents an important platform for extending the practices to other households as part of the formal and informal technology diffusion process. This extension has occurred through formal field days held periodically over the course of the study and informal exchanges between best-bet and non-project households. In the exit interviews, the best-bet households were asked how many other households had approached them about their activities and the nature of the exchanges. Based on these interviews, and also the written records kept by some of the best-bet households, the total number of 'scaleout' households is estimated at between 200 and 250 individuals. The establishment and feeding of forages and cuttings of new forages were the most common technologies about which advice was exchanged. Demand for cuttings at Lompo Tengah has grown to such a level that a small forage cutting market has developed with households charging Rp 100/cutting (the first 100 cuttings are free). One household in Lompo Tengah has provided cuttings to households from as far away as Kalimantan, Kendari, Palu and Lombok. At Mertak, 100% of the households are now accessing perennial tree legumes as a source of cattle feed during the dry season. In Pattappa, all households who have cattle (~50% of total village population) are believed to be growing elephant grass and to have established stalls (kandangs) for the feeding of male animals.

## 4. Discussion

The feedback from the household interviews at the end of the project and 20 months later, combined with the results from monitoring of the on-farm trials indicate that the approach described in this paper has led to: (1) sustained adoption of the full range of best-bet technologies by the 30 participating households with an unambiguous intention to continue these practices into the future; (2) positive production, social and economic impacts; and (3) significant diffusion of the livestock improvement technologies to other households. This success is attributed to a range of techniques designed to promote adoption by smallholders, including the following:

### 4.1. Consideration of system interactions and inter-dependencies

The tight integration and inter-dependencies between the various components of the Eastern Indonesian smallholder enterprise often lead to complex and often counter-intuitive responses to change that require a whole-of-system analysis approach (Stür et al., 2000). For example, the expansion of forage production on the best-bet holdings typically resulted in substantial labour savings as households were spending less time scavenging cut and carry feed and/or shifting cattle to new feed sources. This freed-up labour was often reallocated to improved crop management (e.g. weeding) that in-turn resulted in higher crop yields. That is, the change in forage production affected cattle production, labour usage and availability, household income and crop production. In the case of the Jufri household (Section 3.3), the labour saved from adoption of the best-bet strategies is being used to ferry the wife by motorcycle each day to the school where she teaches, thus generating a second source of household income. Another example is the variable response to displacing food crops with forage crops, and the influence of cultural considerations. In the more marginal cropping environment at Mertak, recent crop failure due to drought encouraged one of the best-bet households to abandon rice production in favour of increased cattle production, using the proceeds from cattle sale to purchase sufficient rice to meet family needs. The modelling work conducted at this site had indicated this to be a lower risk food security strategy. However, while this conversion may in many instances make sound financial sense, most households rejected it on the grounds that they feel more 'secure' and respected by producing their own food.

### 4.2. Desktop modelling of strategies prior to testing on-farm

Previous studies refer to the potential for appropriate simulation models integrated within a broader participatory, farming systems approach, to enhance the uptake of new technologies in smallholder farming systems (Carberry et al., 2004; Matthews and Stephens, 2002; Matthews et al., 2002). However, examples of the application of simulation models that have successfully led to demonstrable impacts on smallholder farming practices are rare. The impact has largely been confined to steering future research direction and training of local researchers (Carberry et al., 2004; Matthews and Stephens, 2002; Matthews et al., 2002). In this study the IAT was developed to capture and integrate current understanding of the farming system and component processes, and to enable analysis of the potential impacts of change. It was realised early on that it is not possible to capture all of the complexity of the component processes and associated interactions of the smallholder farming systems in Eastern Indonesia within an operational model, and an appropriate balance is required between the level of detail employed, precision required, model flexibility and the input data requirements (Thornton and Herrero, 2001). Furthermore, the real power of the IAT lies in being able to compare the production, economic and social consequences of different scenarios and the tradeoffs between crop, forage and cattle production, where the relative differences between scenarios is typically more informative than the output for each individual scenario. With this in mind, the IAT was configured to represent a generic farm and used primarily as a communication tool to inform a broader dialogue between the operator and the smallholders regarding the potential impacts of cattle improvement strategies. The main benefit from the modelling activity was the efficient identification of profitable strategies for subsequent on-farm trials and screening out of less profitable strategies. The modelling also served to promote and educate smallholders and Indonesian staff on farming system approaches and responses. Feedback from the household exit interviews suggested that the modelling activity was not a major factor in promoting adoption per se, with just a small number of households indicating that it had provided 'motivation' to become involved.

### 4.3. Partnerships and household participation

The approach of working closely with individual smallholders is different to conventional approaches that have generally been employed by Government extension agencies in Indonesia. More typically, new technologies that had been 'proven' by research institutions have been extended to large groups of households in a one-size-fits-all approach. This approach reflects the practical and logistical need to service many smallholder households with very limited extension resources. While this may be appropriate and effective for certain 'generic' cattle improvement technologies (e.g. bull provision, disease control) where the impact is typically positive and predictable, other technologies need to be screened and adapted to suit the specific attributes of each farm and the capacity and needs of the individual household. This requires the active participation of smallholder households and access to an 'expert' team of people with the necessary to service an approach involving concurrent research, development and extension activities and multi-disciplinary systems analysis (Horne and Stür, 2003; Shelton et al., 2005). To this end, the study involved a close partnership between the smallholder households and their communities, and a small multi-disciplinary team assembled from key Australian and Indonesian research, development and extension agencies. Smallholders actively participated in every step of the process from benchmarking, identification of cattle production constraints and opportunities, the selection and field testing of best-bet strategies and the extension of technologies to other households. Feedback from household interviews conducted at the end of the project (February 2008) described the approach as having delivered much of lasting benefit because it addressed problems of major significance, adapted solutions to individual capabilities and circumstances and, importantly, provided repetitive reinforcement and technical support over several years.

### 4.4. Incremental approach to on-farm trials

An incremental approach was taken to the development and implementation of the particular package of best-bet strategies that were identified for each participating household. The initial focus was typically to address identified forage supply and quality constraints through modest plantings of selected forages. The confidence and trust arising from the successful employment of these comparatively simple and low risk technologies was then used as the entry point for testing more complex animal management strategies which require long-term planning and investment. Based on the results of the initial modest plantings, the participant households then chose to expand the area of production and focus on a smaller number of preferred species. In many cases the households went onto adopt several best-bet technologies that were not specifically identified in their initial package. One very good example of this development occurred in Mertak village where many of the best-bet households introduced dual purpose food and fodder crops of maize and cassava to provide cattle feed during the mid to late dry season while preserving their tree legume supplies for use later in the dry season. Several Mertak smallholders reported that their experience of trying the new forage sources and the consequent improvement in the condition of their cattle gave them the necessary confidence to invest significant resources in growing crops for cattle forage.

### 4.5. Time and frequency of contact

Shelton et al. (2005) report that most successful examples of adoption of novel forages and animal feeding practices have involved long term commitments from the key stakeholders (i.e. funders, smallholders and collaborating agencies). Such commitment enables the development of effective relationships, time for smallholders to experience the application of the technologies across a range of contrasting season types, capacity building of in-country agency staff and smallholders, and adequate and regular technical support to smallholders when required. Many of the households involved in this study had previously been exposed to aid projects that from their perspective promised something of immediate value but most often delivered little of lasting or tangible benefit. This was eloquently summed up by one householder who described most previous projects that had come to the local village as being like 'pasar malam' (traditional night markets) – set up this afternoon and gone by tomorrow morning. The ongoing commitment of project personnel to working with the households and maintaining access to technical assistance and feedback was seen to strengthen the belief that the project did have something important to offer the community.

### 4.6. Village champions and the value of household to household contact

The extent of scaleout (∼250 households) reported by the best-bet households clearly illustrates the value of on-farm trials in promoting interest and adoption of new technologies by other households in the surrounding community. These trials also served as the centrepiece of field days to which best-bet households from other focus villages were also transported in. These cross-site interactions had the effect of rapidly promoting uptake of certain (successful) best-bet technologies by visiting smallholders. For example, the rapid uptake of tree legumes at Mertak and the use of kandangs (cattle stalls) for feeding and controlled mating at Pattappa were promoted by such exchange visits. These field days also provided an opportunity for participating households to take forage materials (both cuttings and seed) to plant and trial on their own land. The ability of 'champion' or leading smallholders to positively influence adoption by other smallholders was clearly demonstrated by two households in Lompo Tengah which accounted for approximately 100 of the 250 total scaleout smallholder household population.

## 5. Conclusions

This paper describes an approach that has been employed for evaluating and increasing the adoption of livestock improvement technologies that is based on the principles of farming systems and participatory research. The approach involved four main steps; (1) benchmarking the current farming system; (2) identifying constraints to cattle production and strategies to address them; (3) desktop modelling of the production, labour and financial impacts of selected strategies; and (4) on-farm testing and extension of best-bet strategies. The approach has resulted in: (1) sustained adoption of a package of best-bet technologies by the 30 participating smallholder households with an unambiguous intention to continue these practices into the future; (2) positive production, social and economic impacts; and (3) significant adoption/adaption of the livestock improvement technologies by other households exposed to the practices. A follow-on suite of projects is currently scaling this approach out to other regions in Eastern Indonesia and researching the mechanisms and impacts of technology diffusion from the best-bet households to successive generations of scaleout households. The project is also working closely with local institutions to raise awareness of the approach and to incorporate the associated principles and techniques into their standard operating procedures. This is being supported by a significant investment in local capacity building, both of smallholders and supporting agencies.

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## References

Adiku, S.K., Carberry, P.S., Rose, C.W., McCown, R.L., Braddock, R., 1993. Assessing the performance of maize-cowpea intercrop under variable soil and climate conditions in the tropics. In: Proceedings of the 7th Australian Society of Agronomy Conference, September, Adelaide, South Australia, p. 382.

Bouman, B.A.M., Kropff, M.J., Tuong, T.P., Wopereis, M.C.S., ten Berge, H.F.M., van Laar, H.H., 2001. ORYZA2000: modelling lowland rice. Los Banos (Philippines): International Rice Research Institute, and Wageningen: Wageningen University and Research Centre, p 235.

Carberry, P.S., Abrecht, D.G., 1991. Tailoring crop models to the semi-arid tropics. In: Muchow, R.C., Bellamy, J.A. (Eds.), Climatic Risk in Crop Production: Models and Management for the Semiarid Tropics and Subtropics. CAB International, Wallingford, UK, pp. 157–182.

Carberry, P.S., Gladwin, C., Twomlow, S., 2004. Linking simulation modelling to participatory research in smallholder farming systems. In: Delve, R.J., Probert, M.E. (Eds.) Modelling Nutrient Management in Tropical Cropping Systems. ACIAR Proceedings No. 114, pp. 32–46.

Castelan-Ortega, O.A., Fawcett, R.H., Arriaga-Jordan, C., Herrero, M., 2003a. A decision support system for smallholder campesino maize–cattle production systems of the Toluca Valley in Central Mexico. Part I – Integrating biological and socio-economic models into a holistic system. Agricultural Systems 75, 1–21.

Castelan-Ortega, O.A., Fawcett, R.H., Arriaga-Jordan, C., Herrero, M., 2003b. A decision support system for smallholder campesino maize–cattle production systems of the Toluca Valley in Central Mexico. Part II – Emulating the farming system. Agricultural Systems 75, 23–46.

Cramb, R.A., 2000. Processes influencing the successful adoption of new technologies by small holders. In: Stür, W.W., Horne, P.M., Hacker, J.B., Kerridge, P.C. (Eds.), Working with Farmers: the Key to Adoption of Forage Technologies. ACIAR Proceedings No. 95, pp. 11–22.

Devendra, C., Lee Kok, T., Pathmasingham, M., 1973. The productivity of Bali cattle in Malaysia. Malaysian Agricultural Journal 49, 183–191.

Herrero, M., Thornton, P.K., Hoogenboom, G., Ruiz, R., Fawcett, R.H., Jones, J.W., 2002. An integrated modeling platform for animal–crop systems. In: Proceedings of the 17th Symposium of the International Farming Systems Association, November 17–20, 2002, Lake Buena Vista, FL, US, p. 107.

Horne, P., Stür, W.W., 1999. Developing forage technologies with smallholder farmers – how to select the best varieties to offer farmers in Southeast Asia. ACIAR Monograph No. 62, 80pp.

Horne, P.M., Stür, W.W., 2003. Developing agricultural solutions with smallholder farmers – how to get started with participatory approaches. ACIAR Monograph No. 99, 120pp.

Ivory, D.A., 1986. Performance of germplasm in new environments. In: Blair, G.J., Ivory, D.A., Evans, T.R. (Eds.), Forages in Southeast Asian and South Pacific Agriculture: Proceedings of an International Workshop Held at Cisarua, Indonesia, 19–23 August 1985. ACIAR Proceedings No. 12, pp. 61–68.

Keating, B.A., Carberry, P.C., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288.

Makeham, J.P., Malcolm, L.R., 1981. The Farming Game. Gill Publications, Armidale, N.S.W.

Mastika, M., 2003. Feeding strategies to improve the production performance and meat quality of Bali cattle (*Bos sundaicus*). In: Entwistle, K., Lindsay, D.R. (Eds.), Strategies to Improve Bali Cattle in Eastern Indonesia. Proceedings of a Workshop 4–7 February 2002, Bali, Indonesia. ACIAR Proceedings No. 110, Canberra.

Matthews, R.B., Stephens, W. (Eds.), 2002. Crop–Soil Simulation Models: Applications in Developing Countries. CABI Publishing, Wallingford, UK, 277p.

Matthews, R.B., Stephens, W., Hess, T., 2002. Impacts of crop–soil models. In: Matthews, R.B., Stephens, W. (Eds.), Crop–Soil Simulation Models: Applications in Developing Countries. CABI Publishing, Wallingford, UK, pp. 195–205.

McCool, C., 1992. Buffalo and Bali cattle – exploiting their reproductive behaviour and physiology. Tropical Animal Health and Production 24, 165–172.

McCown, R.L., Parton, K.A., 2006. Learning from the historical failure of farm management models to aid management practice. Part 2. Three systems approaches. Australian Journal of Agricultural Research 57, 157–172.

McDonald, C.K., MacLeod, N., Lisson, S., Ash, A., Pengelly, B., Brennan, L., Corfield, J., Wirajaswadi, L., Panjaitan, T., Saenong, S., Sutaryono, Y., Padjung, R., Rahman, R., Bahar, S., 2004. Improving Bali cattle production in mixed crop–livestock systems in eastern Indonesia using an integrated modelling approach. In: Wong, H.K., et al. (Eds.), New Dimensions and Challenges for Sustainable Livestock Farming, Proceedings of the 11th Animal Science Congress, Kuala Lumpur, vol. II, 2004, pp. 116–119.

Norton, G.W., Alwang, J., Masters, W.A., 2006. The Economics of Agricultural Development: World Food Systems and Resource Use. Routledge, New York.

Padjung, R., Natsir, A., 2005. Preliminary survey on Beef/Bali cattle production in South Sulawesi. Report prepared for ACIAR, 15pp.

Paris, T.R., 2002. Crop-animal systems in Asia: socio-economic benefits and impacts on rural livelihoods. Agricultural Systems 71, 147–168.

Peters, M., 2005. Tropical Forages: An Interactive Selection Tool. DPIF (Queensland), CIAT and ILRI, CD-ROM.

Poppi, D.P., McLennan, S.R., Bediye, S., de Vega, A., Zorilla-Rios, J., 1999. Forage quality: strategies for increasing nutritive value of forages. In: Proceedings XVIII International Grassland Congress, Winnipeg, 1997, pp. 307–322.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., Strong, W.M., 1997. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. Agricultural Systems 56, 1–28.

Quigley, S., Poppi, D., Budisantoso, E., Dahlanuddin, M., McLennan, S., Pamungkas, D., Panjaitan, T., Priyanti, A., 2009. Strategies to increase growth of weaned Bali calves. Final report for ACIAR project LPS/2004/023, July 2009, p 92.

Robertson, M.J., Carberry, P.S., 1998. Simulating growth and development of soybean in APSIM. In: Proceedings 10th Australian Soybean Conference, Brisbane, 15–17 September, pp. 130–136.

Robertson, M.J., Carberry, P.S., Chauhan, Y.S., Ranganathan, R., O'Leary, G.J., 2001a. Predicting growth and development of pigeonpea: a simulation model. Field Crops Research 71, 195–210.

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., Brinsmead, R.B., 2001b. Simulation of growth and development of diverse legume species in APSIM. Australian Journal of Agricultural Research 53, 429–446.

Ruthenberg, H., 1980. Farming Systems in the Tropics. Clarendon Press, Oxford.

SCA, 1990. Feeding standards of Australian livestock: ruminants. In: Corbett, J.L. (Ed.), Standing Committee on Agriculture, Ruminants Sub-committee, CSIRO Publications, Melbourne.

Schultze-Kraft, R., 1986. Exotic and native legumes for forage production in Southeast Asia. In: Blair, G.J., Ivory, D.A., Evans, T.R. (Eds.), Forages in Southeast Asian and South Pacific Agriculture: Proceedings of an International Workshop Held at Cisarua, Indonesia, 19–23 August 1985. ACIAR Proceedings No. 12, pp. 36–42.

Shelton, H.M., Franzel, Peters, M., 2005. Adoption of tropical legume technology around the world: analysis of success. In: McGilloway, D.A. (Ed.), Grassland: a Global Resource. Wageningen Academic Publishers, The Netherlands, pp. 149–166.

Stür, W.W., Horne, P.M., Hacker, J.B., Kerridge, P.C., 2000. Working with farmers: the key to adoption of forage technologies. In: ACIAR, Canberra, Australia. ACIAR Proceedings No. 95.

Sukarini, I.A.M., Sastradipradja, D., Sutardi, T., Mahardika, I.G., Budiarta, I.G.A., 2000. Nutrient utilization, body composition and lactation performance of first lactation Bali cows (*Bos sondaicus*) on grass-legume based diets. Asian–Australian Journal of Animal Science 13, 1681–1690.

Talib, C., Entwistle, K., Siregar, A., Budiarti-Turner, S, Lindsay, D., 2003. Strategies to improve Bali cattle in Eastern Indonesia. ACIAR Monograph Series No. 110, ACIAR, Canberra, 94pp.

Thornton, P.K., Herrero, M., 2001. Integrated crop–livestock simulation models for scenario analysis and impact assessment. Agricultural Systems 70, 581–602.

Wirdahayati, R.B., 1994. Reproductive characteristics and productivity of Bali and Ongole cattle in Nusa Tenggara, Indonesia. Ph.D. Thesis, University of Queensland, Brisbane.