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REGULAR ARTICLES

Drivers, challenges and opportunities of forage technology adoption by smallholder cattle households in Cambodia

K Ashley[1] · S Wilson[1] · JR Young[1] · HP Chan[2] · S Vitou[2] · S Suon[2] · PA Windsor[1] · RD Bush[1]

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Abstract Forage technology has been successfully introduced into smallholder cattle systems in Cambodia as an alternative feed source to the traditional rice straw and native pastures, improving animal nutrition and reducing labour requirements of feeding cattle. Previous research has highlighted the positive impacts of forage technology including improved growth rates of cattle and household time savings. However, further research is required to understand the drivers, challenges and opportunities of forage technology for smallholder cattle households in Cambodia to facilitate widespread adoption and identify areas for further improvement. A survey of forage-growing households (n = 40) in July–September 2016 examined forage technology adoption experiences, including reasons for forage establishment, use of inputs and labour requirements of forage plot maintenance and use of forages (feeding, fattening, sale of grass or seedlings and silage). Time savings was reported as the main driver of forage adoption with household members spending approximately 1 h per day maintaining forages and feeding it to cattle. Water availability was reported as the main challenge to this activity. A small number of households also reported lack of labour, lack of fencing, competition from natural grasses, cost of irrigation and lack of experience as challenges to forage growing. Cattle fattening and sale of cut forage grass and seedlings was not found to be a widespread activity by interviewed households, with 25 and 10% of households reporting use of forages for these activities, respectively. Currently, opportunities exist for these households to better utilise forages through expansion of forage plots and cattle activities, although assistance is required to support these households in addressing current constraints, particularly availability of water, if the sustainability of this feed technology for smallholder cattle household is to be established in Cambodia.

Keywords Cambodia · Cattle · Forages · Nutrition · Adoption · Water · Fattening

✉ K Ashley
katherine.ashley@sydney.edu.au

[1] Sydney School of Veterinary Science, Faculty of Science, University of Sydney, Camden, Australia

[2] General Directorate of Animal Health and Production, Phnom Penh, Cambodia

Introduction

Forages have been successfully introduced in a number of countries in Southeast Asia, including Laos, Vietnam, Thailand, Indonesia, Malaysia and the Philippines, with the aim of improving animal nutrition for development of smallholder cattle production and enhancing rural livelihoods (Horne et al. 2005). Forages were introduced to smallholder cattle owning households in Cambodia as early as 2003 under the Livelihood and Livestock Systems Project (LLSP) with the aim of developing improved feeding systems to increase returns of livestock production (Stür et al. 2006). However, forage technology is yet to be fully established and cattle production continues to be constrained by inadequate nutrition due to reliance on traditional feed sources (Bush et al. 2014). Farmers relying on traditional feeding practices including provision of rice straw stored from the previous rice harvest, sourcing native cut and carry grasses from roadsides, paddy lines and communal areas, plus the daily movement of cattle to graze in the field, spend significant amounts of time doing these activities and limit the potential growth of their animals

and the productivity and profitability of their enterprise (Young et al. 2014b).

Previous research in Cambodia investigating adoption of forage technology has shown that the majority of households grow forages on a small scale to supplement existing feed sources (Young et al. 2014b; Ashley et al. 2016). A survey of 1171 forage growing households involved in the 'Best Practice Health and Husbandry of Cattle (BPHH)' project reported an average household forage plot size of 356 m^2 (Young et al. 2014b). A similar study reported an average forage plot size of 400 m^2, with continued use of rice straw, grazing on native pastures and use of crop by-products and crop residues by forage growing households (Ashley et al. 2016). The use of small forage plots and supplementary feed sources with low crude protein (CP) content (Samkol et al. 2015) suggests that the nutritional requirements of cattle are unlikely to be met under current conditions and further work is necessary to increase utilisation of forages by smallholder cattle households.

Forages have been recently introduced to villages involved in the 'Village-based biosecurity for livestock disease risk management in Cambodia (VBLDRM)' project, a 3-year research project facilitated by the General Directorate of Animal Health and Production (GDAHP), Cambodia, and the University of Sydney, Australia, funded by the Australian Centre for International Agricultural Research (ACIAR). In this project, participating households have been provided with forage seed, plus training in the establishment and maintenance of forage plots, the use of forages for feeding cattle and fattening and the sale of seedlings and cut forage. Farmers have also participated in workshops on the production, storage and feeding of silage. These activities are aimed at investigating the hypothesis that improved livestock nutrition enhances rural livelihoods and leads to adoption of animal livestock disease prevention practices (ACIAR 2017).

However, for widespread adoption of forage technology, there are a number of factors that farmers should consider, particularly recognition of the inputs required to establish forage plots. These include the suitability of their land and sufficiency of water to establish and sustain growth of seeds and/or seedlings, and that harvesting is undertaken at the recommended age and height, adequate fertiliser is applied, weeds are removed on a regular basis and the forages are protected from livestock and other animals (Stur and Horne 2001). Secondly, farmers should ensure that the forage area is appropriate for the number of cattle owned and sufficient to meet animal nutrient requirements. Finally, farmers should understand the opportunity costs involved in adopting forages instead of traditional crops of rice, corn and cassava, with particular consideration of animal health, household income and labour demands.

This study investigated the drivers, challenges and opportunities of forage technology adoption and assessed the current utilisation of forages by smallholder cattle households in Cambodia. Information on experiences of adopting forage technology including use of forages for cattle fattening, sale of seedlings and cut forage, plus use of silage, was obtained from farmers participating in the VBLDRM project. The study aimed to improve understanding of farmer motivation in adopting forage technology, identify key issues regarding forage establishment and maintenance and report on opportunities to enhance the current uses of forage technology amongst project households. This information will likely identify areas for further training to improve adoption, utilisation and expansion of forage technology by smallholder cattle households in Cambodia.

Materials and methods

Site selection

The current study selected two villages involved in the VBLDRM project where forage growing had been established by the majority of households and farmers were willing and available to be interviewed. The two villages selected were Sen Ouk village in Tramkok District, Takeo province, and Ampil Chrum village in Tbong Khmum District, Tbong Khmum province (Fig. 1). Sen Ouk village is located west of the Mekong River approximately 75 km south-west of Phnom Penh. Ampil Chrum village is located east of the Mekong River approximately 100 km north-east of Phnom Penh. These villages had previously been selected for involvement in the VBLDRM project based on farmer, village leader and local government commitment to the project, a minimum of 25 smallholder farmers with current or intention to own ≥ 3–4 cattle, land available for forage establishment and year-round access to main roads and markets.

Description of study sites

Both villages form part of the second largest agro-ecological zone (AEZ) in Cambodia, the Plains Zone (AEZ II), an area covering one million hectares where crop production is widespread and has the highest density of cattle, buffalo, pigs and poultry (NIS 2013). The majority of households in both villages are mixed crop-livestock. In Sen Ouk village, rice is the main crop produced whilst corn, cucumber, pumpkin, garlic and chilli are also grown. In Ampil Chrum village, common crops grown include rice, corn, cassava, bamboo, banana, custard apple and frangipani. In both villages, most households own a small number of cattle for cow-calf production and also keep chickens for sale and/or household consumption. Buffalo, pigs and goats are not common in either village.

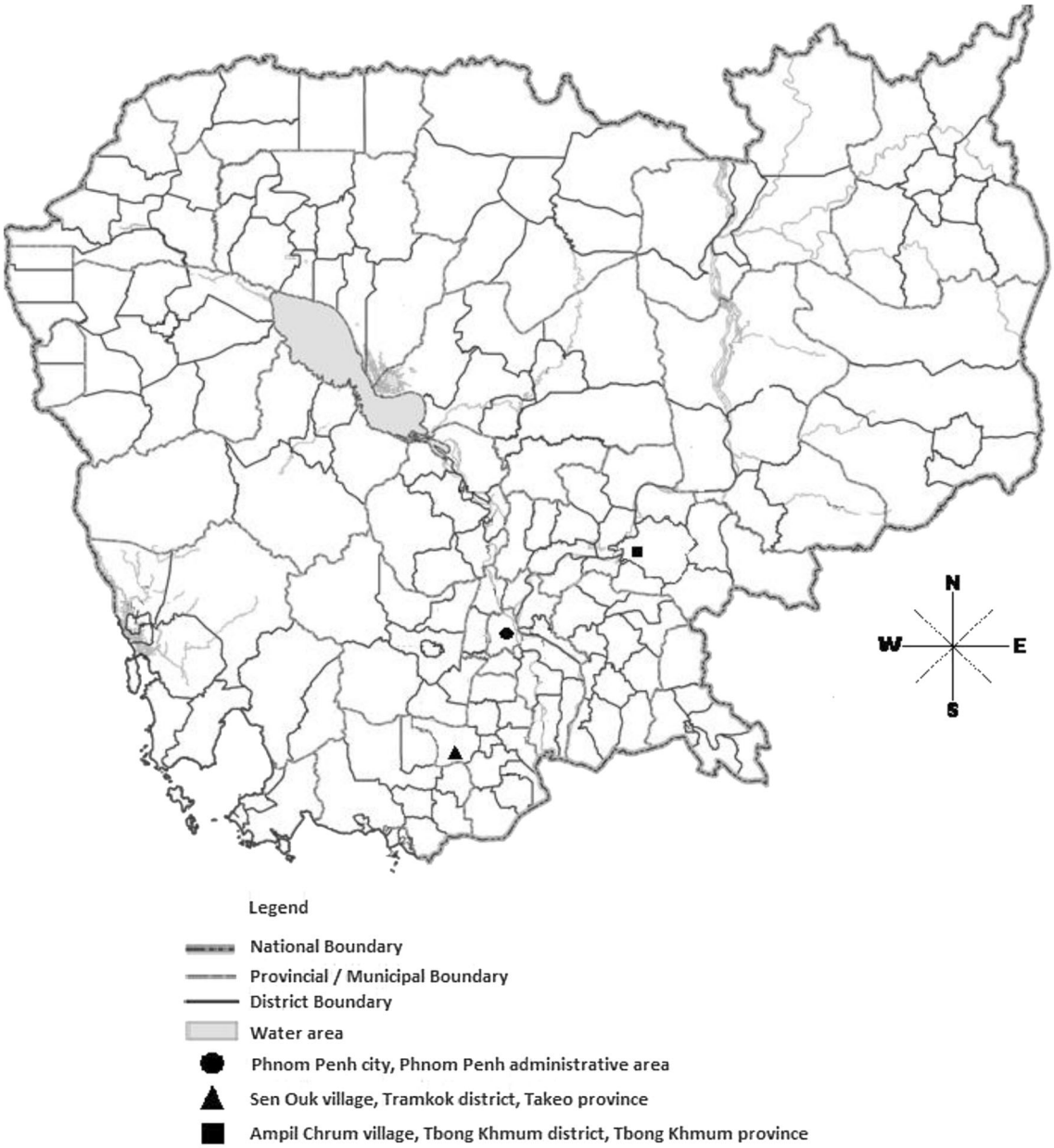

Fig. 1 District map of Cambodia and location of study sites

Survey design

A survey was designed in May 2016 consisting of 40 open and closed questions divided into three parts. Part 1 (forage plot establishment) consisted of 13 questions including number of years growing forages, main reason for forage growing, size of forage area and previous use of this land and use of inputs including land preparation, fertiliser, forage species and planting method, irrigation and fencing. Part 2 (forage plot maintenance and distribution) consisted of 23 questions relating to maintenance of forages and labour requirements, the main benefits and challenges of forage growing and forage distribution (use of forages for fattening, silage and/or selling grass and seedlings). Labour requirements included involvement of household members in forage activities (cutting, weeding, applying chemicals and manure and watering) and total time spent per household. To conclude, part 3 (forage plot expansion) consisted of four questions to assess expansion of forage technology. To determine if expansion of forage plots had occurred since involvement with the project, households were requested to report on the total forage plot area 12 months previously to enable comparison with the current forage plot area. Households were also requested to advise whether they intended to increase forage growing areas and if so, what land they would use, the size of the area (ha) and any potential barriers to expansion.

Survey distribution and data collection

The survey was carried out in both villages at the household level between July and September 2016. From each village, 20 available households were selected from a list of 30 households growing forages, providing a total of 40 households participating in the study. To minimise interviewer bias, one staff member was selected to conduct the survey and received pre-interview training to ensure understanding of the survey methodology and questionnaire. The staff member travelled to each village and conducted semi-structured interviews with one representative of each selected household. Semi-structured interviews were chosen to allow for additional information to be provided (Adams and Lawrence 2014). Interviews were conducted in Khmer language, translated into English and recorded on survey answer sheets. To minimise response bias, interviews were conducted one on one with household representatives to avoid potential influence from other household representatives in survey responses (Groves et al. 2011). All survey answer sheets were collated, and data entered into Microsoft Excel (Excel 2010). Data was analysed using GenStat 14th Edition (VSN International). Differences between population means was assessed using a *t* test assuming equal variances. To compare population proportions for selected responses, a *z*-test was used to detect differences between villages. Descriptive analysis was also employed to compare responses between and within groups.

Results

Forage plot establishment

Household representative(s) and cattle herd size

Of the 40 household representatives interviewed, 20 were female and 20 were male (Table 1). The average age of household representatives was 39 years for females and 46 years for males. Cattle herd size per household ranged from 2 to 20 head of cattle with a mean of 6. At the village level, households in Ampil Chrum village owned more cattle on average (seven head per household) compared to households in Sen Ouk (four head per household) ($P < 0.05$).

Number of years growing forages and main reason for forage plot establishment

On average, households had 1.8 years of experience growing forages. At the village level, households in Sen Ouk had more experience growing forages (3 years) compared to households Ampil Chrum village (0.6 years) ($P < 0.05$) (Table 1). The motivations for households to commence growing forages were to save time feeding cattle (47.5%) and addressing insufficient feed for cattle (30%). However, there were differences at the village level, with time savings as the main driver for households in Ampil Chrum (60%), and insufficient feed for cattle was the main driver for forage adoption in Sen Ouk (45%).

Previous use of land prior to forage establishment

Overall, forages most commonly replaced rice (23%), followed by vegetables, herbs and spices (20%), fruit (15%), corn (13%), cassava (13%), frangipani (7%) and rubber (1%) (Table 2). A small proportion of households established forage plots on land that was previously unused (7%). At the village level, the majority of households in Sen Ouk replaced rice (41%), vegetables, herbs and spices (32%) and corn (15%) with forages. In Ampil Chrum, forages most commonly replaced cassava (30%), fruit (26%) and other crops (18%), including rubber, bamboo and frangipani.

Size of forage area and use of inputs to establish forages

On average, households in Ampil Chrum village reported larger forage plots (5368 m^2) compared to households in Sen Ouk village (2280 m^2) (Table 3). There were differences in use of inputs to establish forage plots. Most households in Ampil Chrum village relied on machinery to prepare the land (90%) whilst households in Sen Ouk village utilised a range of labour sources, including cattle (35%), machinery (25%) or both (20%). Households in Sen Ouk reported higher usage of chemical fertiliser and irrigation (75%) compared to households in Ampil Chrum (20%). Use of manure was also more common in Sen Ouk village compared to Ampil Chrum village where 40% of households did not use manure compared to 5% of households in Sen Ouk. Use of seedlings was more common across all households (82%) compared to seeds (8%). Fencing of forage plot areas was not common in either village (10 and 15%).

Forage plot maintenance and distribution

Maintenance of forages—labour requirements and use of inputs

Overall, adult males were most involved in forage activities (83%) and this was particularly evident in Ampil Chrum where 95% of households reported involvement of this group (Table 4). Over half of all interviewed households (60%) reported involvement of adult females in forage activities, and this was relatively similar between villages (55% in Ampil Chrum and 65% Sen Ouk). Involvement of boys and girls aged less than 18 years in forage plot activities was very low (5%). Total time spent per household tending to forages was

Table 1 Number of interviewed households, gender and age of household representative and main reason for forage establishment

	Sen Ouk	Ampil Chrum	Total
Number of interviewed households (*n*)	20	20	40
Gender of household representative			
Male	8	12	20
Female	12	8	20
Age of household representative (years)			
Male	44 (24–63)	47 (31–64)	46 (24–64)
Female	42 (27–64)	34 (26–43)	39 (26–64)
Number of cattle owned (head)	4a (2–12)	7[b] (3–20)	6 (2–20)
Number of years growing forages	3a (0–6)	0.6b (0–1)	1.8
Main reason for starting to grow forages			
To increase the value of cattle	5% (*n* = 1)	5% (*n* = 1)	5% (*n* = 2)
To improve the health of cattle	0% (*n* = 0)	10% (*n* = 2)	5% (*n* = 2)
To save time feeding cattle	35% (*n* = 7)	60% (*n* = 12)	47.5% (*n* = 19)
Other			
- Insufficient feed for cattle	45%a (*n* = 9)	15%b (*n* = 3)	30% (*n* = 12)
- Advice from another farmer	15% (*n* = 3)	0% (*n* = 0)	7.5% (*n* = 3)
- Support cattle trading business	0% (*n* = 0)	5% (*n* = 1)	2.5% (*n* = 1)
- Followed instructions from project	0% (*n* = 0)	5% (*n* = 1)	2.5% (*n* = 1)

Different lowercase letters indicate a significant difference of $P < 0.05$

1.02 h per day and 0.21 h per animal. Use of chemical fertiliser, manure and irrigation to maintain forages differed between villages. A number of households in Sen Ouk village applied either urea (40%) or manure (40%) after cutting each month. This practice was not reported by any households in Ampil Chrum village. Irrigation of forage plots was more common in Sen Ouk village (60%) compared to Ampil Chrum (25%) during the dry season.

Benefits and challenges associated with forage growing

Overall, time savings was the main benefit reported by all households (73%) followed by cattle gaining weight and increasing in value (17%) and other (10%) (Table 5). Water availability was reported as the main challenge for 40% of interviewed households. A large proportion of households (42.5%) reported that they had not experienced any issues

Table 2 Previous use of land

	Sen Ouk	Ampil Chrum	Total
Total number of responses*	34	27	61
Previous use of land			
Rice	41%a (*n* = 14)	0%b (*n* = 0)	23% (*n* = 14)
Corn	15% (*n* = 5)	11% (*n* = 3)	13% (*n* = 8)
Cassava	0%a (*n* = 0)	30%b (*n* = 8)	13% (*n* = 8)
Vegetables, herbs and spices	32%a (*n* = 11)	4%b (*n* = 1)	20% (*n* = 12)
Fruit	6% (*n* = 2)	26% (*n* = 7)	15% (*n* = 9)
Frangipani	0% (*n* = 0)	15% (*n* = 4)	7% (*n* = 4)
Rubber	0% (*n* = 0)	3% (*n* = 1)	2% (*n* = 1)
Unused land	6% (*n* = 2)	11% (*n* = 3)	7% (*n* = 5)
Total	100% (*n* = 34)	100% (*n* = 27)	100% (*n* = 61)

Households were able to provide more than one response for previous use of forage plot land. Different lowercase letters indicate a significant difference of $P < 0.05$

Table 3 Size of forage plot and use of inputs

	Sen Ouk	Ampil Chrum	Total
Number of interviewed households (*n*)	20	20	40
Average size of forage plot (m^2)	2280	5368	0.38
Range in size of forage plot (m^2)	500–20,000	800–30,000	
Inputs			
Ploughing			
- Using machine (hand tractor/tractor)	25%a (*n* = 5)	90%b (*n* = 18)	57% (*n* = 23)
- Using cattle as draft	35%a (*n* = 7)	0%b (*n* = 0)	17% (*n* = 7)
- Using machine and cattle	20%a (*n* = 4)	0%b (*n* = 0)	10% (*n* = 4)
- Using machine and by hand	10% (*n* = 2)	5% (*n* = 1)	8% (*n* = 3)
- By hand	0% (*n* = 0)	5% (*n* = 1)	3% (*n* = 1)
Did not plough	10% (*n* = 2)	0% (*n* = 0)	5% (*n* = 2)
Fertiliser	75%a (*n* = 15)	20%b (*n* = 4)	48% (*n* = 19)
Manure	95%a (*n* = 19)	60%b (*n* = 12)	78% (*n* = 31)
Forage			
- Seeds	0% (*n* = 0)	15% (*n* = 3)	8% (*n* = 3)
- Seedlings	95%a (*n* = 19)	70%b (*n* = 14)	82% (*n* = 33)
- Both	5% (*n* = 1)	15% (*n* = 3)	10% (*n* = 4)
Irrigation	75%a (*n* = 15)	20%b (*n* = 4)	48% (*n* = 19)
Fencing	10% (*n* = 2)	15% (*n* = 3)	13% (*n* = 5)

Different lowercase letters indicate a significant difference of $P < 0.05$

growing forages. When comparing these results against the average years of experience growing forages, the majority of households that reported no issues had less experience on average (1.67 years) compared to households reporting that water availability was the main challenge (1.81 years).

Distribution of forages (fattening, sale of cut grass and/or seedlings, silage)

A total of 10 households (25%) reported using forages for cattle fattening including two households in Sen Ouk and

Table 4 Labour requirements and inputs to forage plot maintenance

	Sen Ouk	Ampil Chrum	Total
Number of interviewed households (*n*)	20	20	40
Household members involved in forage activities			
Adult male (> 18 years old)	70%a (*n* = 14)	95%b (*n* = 19)	83% (*n* = 33)
Adult females (> 18 years old)	65% (*n* = 13)	55% (*n* = 11)	60% (*n* = 24)
Boys (< 18 years old)	0% (*n* = 0)	5% (*n* = 1)	5% (*n* = 1)
Girls (< 18 years old)	5% (*n* = 1)	0% (*n* = 0)	5% (*n* = 1)
Average time spent per household maintaining forages (hours)			
Per day	0.97	1.06	1.02
Per animal	0.25	0.17	0.21
Use of inputs on a continual basis			
Urea (one time per month after cutting)	40%a (*n* = 8)	0%b (*n* = 0)	20% (*n* = 8)
Manure (one time per month after cutting)	40%a (*n* = 8)	0%b (*n* = 0)	20% (*n* = 0)
Irrigation			
- Dry season	60%a (*n* = 12)	20%b (*n* = 4)	40% (*n* = 16)
- Wet season	5% (*n* = 1)	0% (*n* = 0)	2.5% (*n* = 1)

Households reported involvement of more than one family member in forage plot maintenance. Different lowercase letters indicate a significant difference of $P < 0.05$

Table 5 Benefits and challenges of forage growing

	Sen Ouk	Ampil Chrum	Total	Av. years' experience
Number of interviewed households (*n*)	20	20	40	
Main benefit of forage growing				
Family saves time	65% (*n* = 13)	80% (*n* = 16)	73% (*n* = 29)	1.73
Cattle gain weight and increase in value	20% (*n* = 4)	15% (*n* = 3)	17% (*n* = 7)	1.88
Cattle can get pregnant more often	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	–
Other	15% (*n* = 3)	5% (*n* = 1)	10% (*n* = 4)	1.25
Main challenge of forage growing				
Water availability	55% (*n* = 11)	25% (*n* = 5)	40% (*n* = 16)	1.81
Land availability	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	–
Lack of labour	10% (*n* = 2)	0% (*n* = 0)	5% (*n* = 2)	2.33
Access to seed/seedlings	0% (*n* = 0)	0% (*n* = 0)	0% (*n* = 0)	–
Have not experienced any issues	30% (*n* = 6)	55% (*n* = 11)	42.5% (*n* = 17)	1.67
Other				
- Natural grass competing with forages	5% (*n* = 1)	0% (*n* = 0)	2.5% (*n* = 1)	3
- Lack of fencing to protect forages	0% (*n* = 0)	10% (*n* = 2)	5% (*n* = 2)	1
- Cost of irrigation	0% (*n* = 0)	5% (*n* = 1)	2.5% (*n* = 1)	1
- Lack of experience	0% (*n* = 0)	5% (*n* = 1)	2.5% (*n* = 1)	0

eight households in Ampil Chrum. No households reported making of silage. However, a small number of households (7.5%) reported that they were interested in producing silage in the future to provide to cattle during the dry season. Income from sale of cut grass and seedlings was not widespread. A small proportion (*n* = 2) reported income from sale of seedlings, and another two households (5%) reported income from sale of both seedlings and cut grass. The two households in Sen Ouk village earning income from the sale of seedlings advised that the seedlings were sold for one US cent each to five other households in another village in the same district, and total income was USD30 and USD100, respectively. For the two households that sold both seedlings and cut grass, one household in Ampil Chrum sold US$10 worth of seedlings to two households in Kampong Cham province and also sold 200 kg of cut grass to one household in Kampong Cham but could not recall the income received. The remaining household in Sen Ouk village reported substantial income from sale of seedlings and cut grass, earning US$5000 per year selling seedlings to approximately 1000 households and another US$2000 per year selling cut grass to approximately 200 households. For the 36 households that did not report income from the sale of grass or seedlings, a large proportion of households (50%) gave seedlings away for free to neighbours, relatives and other households both within and outside the village. A small percentage (12.5%) also gave away grass for free to other households by allowing them to utilise excess forage that they did not require and/or forage that 'had become old and the cows did not like to eat'.

Forage plot expansion

Households reported an average forage area of 1900 m^2 in the previous 12 months with households in Sen Ouk reporting 1600 m^2 of forage and households in Ampil Chrum reporting 2200 m^2 of forage. Forage expansion had occurred in both villages but was greater in Ampil Chrum village where 70% of households increased their forage areas by 5100 m^2 on average compared to 50% of households in Sen Ouk that expanded forage areas by 1400 m^2 ha on average. The majority of households (72.%) responded 'yes' that they intended to increase the size of their forage area plots by converting existing cropping areas (rice, corn and custard apple) into forage or by utilising currently unused land with intended increases ranging from 1000 to 5000 m^2. However, for some households this was dependent on factors including available labour (*n* = 2), land availability (*n* = 1), funds to build a pond close to the forage plot (*n* = 1), money for ploughing (*n* = 2), the success of this year's forages (*n* = 1) and herd size (*n* = 1). For those households that responded 'no' (27.5%), lack of

available land ($n = 2$), lack of labour ($n = 1$) and the low price of cattle ($n = 1$) were provided as reasons for non-expansion.

Discussion

This study provides insights into the reasons for adoption of forages as a cattle feed by smallholder households in Cambodia. Time savings was the main driver for adoption of forages, as is consistent with previous research in Lao PDR and Vietnam where the opportunity to save time and labour was the main motivational driver of forage adoption by livestock owners (Millar and Connell 2010; Stur et al. 2013). However, differences at the village level indicated that limited feed availability for cattle was also a contributing factor to forage adoption, with 45% of households in Sen Ouk citing insufficient feed as the main reason they commenced growing forages. These households reported experiencing difficulties providing sufficient feed for cattle by their previous practice of using natural grass, rice straw and/or rice bran. Alternatively, for households in Ampil Chrum, it may be the case that whilst traditional feed sources were available, growing forages closer to home is more time efficient and thus reduced time spent feeding cattle.

Other factors were also relevant in the adoption of forages by smallholder cattle households. A small number of farmers recognised the value of forages in increasing the value (5%) and improving the health (5%) of cattle. Established forage growers also appeared relevant to forage adoption by households in Sen Ouk village, with three farmers stating that they had been influenced by observing other households in the village that had commenced growing forages after witnessing that it was 'easy for other farmers growing forages to feed their cattle'. Observing the success of a technology before adoption is commonly associated with forages as the growing of forages may be unfamiliar and the long-term benefits not immediately obvious (Stür et al. 2002).

Forages replaced a variety of other on-farm crops, and this varied between and within villages, highlighting the diverse nature of mixed crop-livestock systems in rural Cambodia. It was common for households in Sen Ouk to replace rice and vegetables, herbs and spices with forage whilst households in Ampil Chrum converted cassava and fruit areas into forage plots. This was largely due to the location of Sen Ouk in the lowland Mekong floodplain where rice and vegetable growing is dominant. Ampil Chrum is representative of the upland Mekong floodplain where agro-industrial crops (e.g. rubber and cassava) are more commonly grown (Ros et al. 2011). For households replacing crops with forage, a number of factors may have contributed to this decision. Higher returns from cattle compared to most crops was likely a driver for establishing forages to support cattle raising. A number of households in Ampil Chrum reported that low market prices for certain crops (cassava and frangipani) provided incentives to utilise land for growing forages. Previous research comparing the financial benefit of establishing forages on a small area of land (400 m^2) previously utilised for rice production and fattening 2.8 head of cattle over a 6-month period resulted in a net profit of US$139.01 (Ashley et al. 2016). However, further research is required to investigate these findings, and the authors are currently undertaking a gross margin (GM) analysis to compare the profitability of forage-based cattle raising and crops. The results of the GM analysis will provide a more accurate assessment of the opportunity costs of forage technology adoption for smallholder cattle households in these villages.

Variable inputs to forage plot establishment and maintenance between villages, particularly the use of machinery, fertiliser (chemical and organic) and irrigation, were observed. Households in Sen Ouk relied more on traditional ploughing methods, chemical fertiliser, manure and irrigation to establish and facilitate growth of forages. As these households had smaller forage plots, their utilisation of cattle for ploughing was feasible and use of chemical fertiliser, manure and irrigation was required to address the low fertility of the sandy soils of rain-fed lowland areas (Blair and Blair 2014). In contrast, households in Ampil Chrum relied primarily on machinery (hand tractor or tractor) to plough the land and utilised chemical fertiliser and manure less frequently. This may reflect that ploughing with cattle was less feasible for large forage plots and that the fertile red basalt soils of this region (Saeki et al. 1959) require less fertiliser to provide adequate nutrients for plant growth.

Similarities in labour requirements for maintenance of forage plots were observed between villages. Adult males were most involved in forage activities (83%), and households spent approximately 1 h per day maintaining forage plots (cutting, weeding, applying chemicals and manure and watering). There was minimal involvement of children in forage activities (5%). These findings are consistent with previous research in Cambodia, Vietnam and the Philippines indicating reduced involvement of children in feeding cattle due to forage adoption (Bosma et al. 2003; Dimang et al. 2009; Maxwell et al. 2012; Young et al. 2014a; Ashley et al. 2016) and provide further evidence of the benefits of forage technology for families in smallholder cattle households.

A number of challenges to the sustainability of forages were reported by households in this study, including water availability, irrigation costs, lack of labour, lack of fencing to protect forages, competition from natural grasses and lack of experience. Water availability was the main issue reported by households and, in particular, those in Sen Ouk. Whilst the project has attempted to address this issue via the installation of water wells in both villages and promotion of installation of ponds and irrigation of forages, the benefits of these solutions (i.e. extended forage growing season and increased yields)

largely depend on availability and access to these resources. At present, water obtained from the water wells is at the discretion of the two households who own the land where the water wells have been built. These households have reported that the water is limited and that they are unsure as to the quality of the water for use on forages and for consumption by cattle. Neighbouring households have also reported they have restricted access to these water wells despite the directive to the village chief from project staff that the installed wells are a village resource available to all households. This issue was reported from a previous project conducted in the Tonle Sap Basin where community management of irrigation resources had been poor due to lack of cooperation between neighbouring farmers in the distribution of water (CDRI 2010). To manage this issue, installation of the ponds may be an alternative solution by providing households with an appropriate water source and reducing the need for shared allocation of water resources. However, installation of ponds is often only available to those households able to pay for pond construction and purchasing of the pump and pipes required to facilitate irrigation of forage areas. Soil type is an important consideration especially for those households in Sen Ouk with sandy soils that may not be suitable for pond construction. For those households unable to access water from project-supported water wells and/or construct their own pond and pump water to forage plots, there appears no other option but to rely on rain-fed irrigation during the wet season and hope that forages are able to survive the dry season with limited rainfall (< 50 mm average monthly rainfall from December to May) and hot temperatures (38° average monthly temperature in April). For a number of households in Ampil Chrum village, forages established the previous wet season died during the dry season, resulting in these households having to re-establish their forage plantations during the following wet season. However, for households in Sen Ouk village, this was addressed by irrigation to ensure forages survived the dry season. Whilst irrigation should be promoted to households in Ampil Chrum to address water availability, consideration of the costs associated with irrigation, particularly for low-income households, is advised. For these households, conservation of forages as silage to utilise over the dry season may be a more appropriate solution and has been promoted in other countries with extended dry seasons, ensuring livestock have continuous access to high-quality forage (Reiber et al. 2010; Marsetyo et al., 2013). As no households in the current study reported making silage despite having participated in the silage training, further workshops, particularly involving those households that expressed interest in producing silage for cattle, is advised.

The use of forage technology amongst households involved in this studied varied. The majority of households (75%) reported growing forages solely for feeding their own cattle with only a small number of households reporting using forages for fattening and sale (25%). Based on the reported average herd size of six animals, the average forage plot area per animal (633 m^2) meets the recommended 500–1000 m^2 required per animal for cow-calf production (Stür et al. 2006). However, for fattening of cattle where a forage plot area of 800–1000 m^2 per animal is recommended (Stür et al. 2006), current forage production is insufficient to support this activity for an average household. Therefore, expansion of forage plot areas is required to better support cattle fattening activities and ensure cattle receive the recommended daily DM feed intake of 2.5–3.5% body weight to facilitate adequate growth (Stur and Horne 2001). In Vietnam, research conducted by the International Centre for Tropical Centre (CIAT) has shown that forages can provide an important mechanism for farmers to transform their smallholder system into a more specialised enterprise (Stur et al. 2013). A project conducted in the Ea Kar District in the central highlands of Vietnam reported that whilst cattle fattening was a relatively new concept with only three households fattening cattle at project commencement in 2003, by 2007 approximately 501 households had specialised in production of stall-fed cattle through feeding of ad libitum fodder (approximately 32 kg of fresh grass per animal per day (Stur et al. 2013). In Cambodia, the feeding forages for cattle fattening and sale is still relatively new, although evidence is accumulating that widespread cattle fattening may be achievable if training and support is provided, as occurred in Vietnam. Further extension work is required to encourage farmers to expand forage plots, increase forage production and shift from maintenance-based feeding methods to more targeted forage-based feeding to allow for specialisation of these smallholder cattle systems.

Sale of grass and/or seedlings was not widespread (10%) amongst interviewed households. This may reflect that most households may be unaware of the commercial value of forage and/or lack access to forage markets. Potential opportunities exist for these households to grow forages beyond providing nutrition to their own cattle, taking advantage of the high prices offered for seedlings (40 riel per seedling) and cut grass (US$2.50 per bundle). For example, one household reported earnings of US$5000 per year from sale of seedlings and US$2000 per year from sale of cut grass alone, highlighting the potential income from developing a forage business activity. However, connection to markets is required for households to produce, sell and generate income from cut forage grass and/or seedlings. For households in Sen Ouk village, cut grass is able to be sold at the nearby Ang Ta Som Market (approximately 20 km) and households have the opportunity to sell excess forage there daily. For households in Ampil Chrum village, earning income from sale of seedlings and or cut grass is limited due to their relative isolation from other villages and lack of an available market in the nearest town centre of Kampong Cham (approx. 20 km). These households often rely on cattle traders to generate interest in outside areas

in buying their forages, and further work is required to identify potential customers, either via direct sale or through forage traders that collect and sell via forage markets. A number of households also reported giving seedlings and grass away for free to other households. Whilst there appears to be an opportunity cost associated with this practice, this is likely to provide important community benefits from forages with households able to support each other in overcoming the difficulties of feeding cattle and improving cattle raising practices.

The current study demonstrates that there are a number of drivers, challenges and opportunities associated with forage adoption amongst smallholder cattle households in Cambodia. Reducing labour requirements of feeding cattle, minimal involvement of children in forage activities and potential opportunities to earn income from sale of cut grass and seedlings are evidence of benefits for households in adopting forages for cattle. However, to achieve and sustain the reported benefits of growing forages, the challenges reported by households in this study need to be addressed. Whilst there are many variables for Cambodian smallholder cattle-raising households to consider when contemplating adoption of forage technology, this study presents valuable information that inform future forage dissemination and extension activities, and is of relevance to policy development aimed at improved rural livelihoods and reducing food insecurity in developing countries.

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Compliance with Ethical Standards

Statement of human rights Human ethics approval for this study was obtained from the University of Sydney Ethics Committee (project no. 2014/783) in compliance with State Acts and National Codes of Practice. Informed consent was obtained from all individual participants included in the study. This article does not contain any studies with animals performed by any of the authors.

Conflict of interest The authors declare that they have no conflict of interest.

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