THE ROLE OF IRRIGATED FODDER PRODUCTION TO SUPPLEMENT THE DIET OF FATTENING SHEEP BY SMALLHOLDERS IN SOUTHERN ETHIOPIA

[PAPEL DE LA PRODUCCIÓN DE FORRAJE BAJO RIEGO PARA SUPLEMENTAR LA DIETA DE OVINOS DE ENGORDE POR PEQUELOS PRODUCTORES EN EL SUR DEL ETIOPIA]

M. Bezabih[a,b,*], A.J. Duncan[a], A. Adie[a], K. Mekonnen[a], N.A. Khan[a] and P. Thorne[a]

[a] *International Livestock Research Institute, P.O. Box 5689, Addis Ababa, Ethiopia. Emails: derseh7@yahoo.com, a.duncan@cgiar.org, a.adie@cgiar.org, k.mekonnen@cgiar.org, nak126@gmail.com, p.thorne@cgiar.org*
[b] *Hawassa University, department of Animal and Range Sciences, P.O. Box, 5, Hawassa, Ethiopia*
[*] *Corresponding author*

SUMMARY[1]

Feed shortage and poor quality of available feeds are major constraints for livestock production in the highlands of Ethiopia. A trial was conducted to assess if producing irrigated oat-vetch fodder during the dry period could adequately supplement the diet of fattening sheep and generate additional income for smallholders. A total of 14 farmers and 70 sheep (5 per farmer) were involved in the trial. The farmers supplemented their fattening sheep with 200 g of irrigated oat-vetch fodder per day for about 70 days. The mean daily body weight gain of the fattened sheep ranged from 52 to 110 grams. The partial budget analysis revealed that while farmers with good feeding management could earn an additional income in the range of ETB 55 – 161 per sheep, farmers with the lower rate of weight gain could lose up to ETB 58 per sheep unless purchase and sale prices remained constant. Sheep prices do, however, fluctuate, peaking during major holiday periods occurring during the dry season. Therefore, timing of the fattening period is essential to profitability, and supplemental irrigated fodder production offers smallholders opportunities to produce good quality feed and target favourable markets for fattened animals.

Key words: Doyogena sheep; oat-vetch; protein; supplementation; manual pumps; irrigation.

RESUMEN

La escasez de piensos y la escasa calidad de los piensos disponibles son limitaciones importantes para la producción pecuaria en las tierras altas de Etiopía. Se realizó un ensayo para evaluar si la producción de forraje de avena de regadío durante el período seco podría complementar adecuadamente la dieta de las ovejas de engorde y generar ingresos adicionales para los pequeños agricultores. En el ensayo participaron un total de 14 agricultores y 70 ovejas (5 por agricultor). Los agricultores suplementaron sus ovejas de engorde con 200 g de forraje de avena irrigada por día durante unos 70 días. La ganancia media diaria de peso corporal de las ovejas engordadas varió de 52 a 110 gramos. El análisis parcial del presupuesto reveló que si bien los agricultores con un buen manejo de la alimentación podrían obtener un ingreso adicional en el rango de ETB 55-161 por oveja, los agricultores con ovejas con menor tasa de ganancia de peso podrían perder hasta 58 ETB por oveja a menos que los precios de compra y venta siguieran siendo constante. Los precios de las ovejas, sin embargo, fluctúan, alcanzando un máximo durante los períodos de vacaciones importantes que ocurren durante la estación seca. Por lo tanto, el momento del año para el período de engorde es esencial para la rentabilidad, y la producción suplementaria de forraje de regadío ofrece a los pequeños productores la oportunidad de producir piensos de buena calidad y orientar los mercados favorables para los animales engordados.

Palabras clave: oveja Doyogena; avena; proteína; suplementación; bombas manuales; irrigación.

[1] *Submitted June 14, 2016 – Accepted October 05, 2016.*

INTRODUCTION

The mixed crop livestock system in Ethiopia is characterized by subsistence farming with high population pressure, shrinking land size for crop cultivation and grazing per household, feed scarcity, land degradation and loss of soil fertility (Haileslassie *et al.,* 2005). Although livestock production plays an important role in the farming system, productivity has remained suboptimal due to feed, disease, genetics, services and market constraints. Shortage of feed has emerged as the major constraint for livestock production in the highlands of Ethiopia (Desta and Oba, 2004) and crop residues have become a major source of feed as grazing lands diminish (Mekasha *et al.,* 2014). However, the nutritive value of crop residues is generally poor with low organic matter digestibility (less than 50%), high fiber (NDF>70%) and low crude protein contents (mostly 3-5%) (Gizachew and Smit, 2005). Moreover, there is a distinct seasonality in the availability of feeds in the highlands, reaching peak levels towards the end of the rainy season and critically low levels towards the end of the long dry period when green forage is scarce (Gizaw *et al.,* 2012; Mekonnen *et al.,* 2014). This latter part of the year is also the time when the quality of available feeds is at its minimum, mainly composed of the above mentioned low quality crop residues (Abegaz *et al.,* 2007). The combined effect of feed scarcity and poor feed quality during the dry period presents a serious challenge to livestock owners to meet the energy and nutrient demands of their animals (Yayneshet *et al.,* 2008). As a result the livestock population often experiences cyclic loss of body condition following seasonal feed production patterns (Bezabih *et al.,* 2014), which influences the supply and price of livestock products in the local market (Kocho *et al.,* 2011). For instance, the price of fattened sheep commonly reaches peak levels during major holiday markets occurring during the long dry period (ELMIS, 2015).

Small-scale irrigation has potential to support intensification of the crop-livestock system in the highlands of Ethiopia (Gebregziabher *et al.,* 2009; Getnet *et al.,* 2014; Hagos and Mamo, 2014). There is currently an emphasis in the country to expand small- and medium-scale irrigation agriculture in rural areas to improve farm productivity and provide resilience to the negative effects of climate change (Gebregziabher *et al.,* 2009). Farmers in the highlands generally have different levels of experience using shallow wells, streams, rivers and ponds to irrigate their land for vegetable and other crop production (Worqlul *et al.,* 2015). Such irrigation practices inherently produce feed biomass as a byproduct (grass along water canals and field plots, inedible vegetable waste, and crops harvested-green) which serve as a source of supplemental feed (Haileslassie *et al.,* 2009). Production of improved fodder using irrigation alongside food crops is nonetheless not commonly practiced despite the scarcity of green fodder during dry periods. This may be due to lack of awareness or the impression that production of fodder using irrigation is not economically attractive. However, considering the relatively better price for fattened animals in the dry period and the limitation of fodder during these times, irrigated fodder production combined with fattening may enable farmers to target market niches that generate additional income and diversify their livelihoods.

There is limited participatory research conducted in this regard which could provide farmers the opportunity to assess the benefits of supplemental irrigated fodder production to improve the productivity of livestock and income of farmers. Supplementing crop residue basal diets with green fodder, particularly with that of legumes, is considered as an important remedy to increase the nitrogen and soluble sugar content in the diet of ruminants (Oosting *et al.,* 2011). We therefore hypothesized that supplemental fodder production using irrigation could be an attractive option to enhance both the feed resource base, the nutrition of livestock and the income of farmers. To test this hypothesis an action research study was conducted, whereby farmer groups experimented with irrigated oat-vetch fodder production and sheep fattening. The objectives of the study were to assess 1) the performance of irrigated oat-vetch fodder as a source of energy and protein supplement, 2) the type and quality of feed resources available for sheep and 3) evaluate the performance of fattening sheep supplemented with irrigated oat-vetch fodder and the potential of off-season sheep fattening as a source of income for smallholders

MATERIALS AND METHODS

Study site

The study was conducted in two districts (woredas), namely Lemo and Angacha, located at 240 to 264 km south of Addis Ababa between January and August 2014. The two woredas are among the most densely populated areas in the country and have similar agroecology with mean daily minimum and maximum temperatures of 14 and 26 ^{0}C, respectively. During the trial period the mean annual rainfall in the area was 1100 mm. The farmers in both woredas practice mixed crop-livestock farming as their main livelihood. The main crops grown include wheat, barley, maize, teff, faba bean, field pea, fruits and vegetables, while the livestock species kept include cattle, sheep, goats, poultry and some equids.

Lemo is an action site for the research project called Africa RISING (Africa Research in Sustainable Intensification for the Next Generation), which is being led by ILRI in Ethiopia and financed by the USAID Feed the Future initiative. The project conducts participatory action research on technologies and production options for a sustainable intensification of the crop-livestock mixed farming system in the Ethiopian highlands. Within Lemo woreda the project has selected and used two kebeles (Jawe and Ganna) as implementation sites. Angacha is an adjacent woreda sharing borders with Lemo. Farmers in Angacha woreda have better experience of small-scale irrigation using shallow wells and streams than those in Lemo. A local NGO (Food for the Hungry Ethiopia) has introduced manual water lifting pumps (rope and washer) in this woreda, which have helped the farmers to adopt small-scale irrigation at a wider scale. On the other hand the farmers in Lemo woreda have limited experience of small-scale irrigation. However, over the last three years they have been sensitized through the Africa RISING project to practice small-scale irrigation and have been provided with treadle pumps. The two kebeles in Lemo (Africa RISING kebeles: Jawe and Ganna) and Kerekicho kebele in Angacha were selected to conduct this trial.

Study plan and measurements

At the beginning of the study, a village level meeting was conducted with farmers in the three kebeles and they were briefed about the proposed irrigated fodder and fattening trial. A total of 14 farmers (seven from each woreda) were selected. The farmers were selected based on their interest to try production of supplemental irrigated fodder in their plots and availability of irrigation water. Afterwards, each farmer prepared a plot of land and planted oat (*Avena sativa*) and vetch (*Vicia villosa*) fodder (intercropped) with a seeding ratio of 3:1 by weight. The size of the plot was estimated to produce enough irrigated oat-vetch fodder to supplement five fattening sheep at a level of 200 g DM/head/day for 60 days. The farmers used shallow wells to irrigate the plot and grow the fodder. The performance of oat-vetch produced was estimated at the flowering stage by taking samples from four randomly placed 0.5x0.5 m quadrats on each farmer's plot. Representative samples were taken once a week and bulked over the feeding period for nutrient analysis.

Each farmer received five male castrated sheep through a loan for fattening in the month of May. The sheep were of the local Doyogena breed (large indigenous sheep), with a mean weight of 30±1.4 kg. The sheep were purchased from a farmers' cooperative engaged in community based Doyogena sheep breeding program at rate of around 43 Ethiopian birr (ETB) per kg of live weight taking into account market prices at the time. The sheep were sourced from the cooperative to obtain better performing animals for the fattening and also to create a link between the cooperative and producer farmers. The animals were dewormed against internal parasites with Albendazole (15mg/kg) upon arrival at the individual farmers' fields. The farmers were trained to prepare separate pens and feeding troughs for the animals, and after a week of adaptation, the fattening regime was started. During the fattening period, the sheep were fed with locally available feed resources (mainly natural pasture, crop residues and fodder leaves) following the local management practice. Each sheep was supplemented with 200 g DM of oat-vetch fodder (10 MJ ME/kg DM), 150 g of wheat bran (10.7 MJ ME/kg DM), 50 g of Noug cake (8.3 MJ ME/kg DM), and 7.5 g of common salt (NaCl). The supplement was given in the afternoon feeding sessions after the sheep were fed on the locally available feed resources in the morning. Research assistants visited each farmer's house once per week and recorded the weight of the sheep, their health status and overall management. During their visit the assistants provided advice and guidance on the housing and feeding management of the sheep whenever improvement was necessary. Sick-animals were treated by veterinary assistants through regular visits and telephone calls whenever disease symptoms were reported by farmers. After 70 days of feeding, the sheep reached acceptable weight range and the farmers sought a market to sell them out.

Nutritional quality of available feed resources

During the regular visits to the farmers' houses, feed samples (about 50-100 g) were collected from each locally available feed consumed by sheep. Fresh samples were sun-dried under shade on the site and bulked by species. After thoroughly mixing the bulked samples, a subsample of about 400 g was put in a paper bag and brought to the laboratory for chemical analysis. The samples were analyzed for organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin, crude protein (CP), and minerals following standard procedures (AOAC, 1990; Van Soest *et al.*, 1991). Dry matter digestibility (DMD) of the feed samples was predicted according to Oddy *et al.* (1983) as follows: DMD % = 83.58 – 0.824ADF% + 2.626N%, whereas Metabolizable energy (ME) levels were derived using the formula ME concentration (MJ/kg DM) = 0.17×DMD% - 2.0 (Freer *et al.*, 1997).

Focus group discussions and farmers' visits

In the middle of the study, two focus group discussions (FGD) and farmers' experience sharing visits were conducted. The aim was to gather feedback from participant farmers about the practice of growing irrigated fodder and sheep fattening. The first farmers' visit and FGD took place in the Angacha district when the irrigated fodder was almost ready for use, and the focus of this discussion was on irrigation practices, water lifting pumps, management of fodder plots and fattening animals. The second FGD took place in Lemo district when the fattening sheep were ready for sale, and the discussion focused on the fattening process, challenges, opportunities and future directions.

Data analysis

The data on the irrigated fodder biomass produced, the nutritive quality of feeds, the weight gain records, and the costs incurred during the fattening process were summarized using descriptive statistics. The dry matter yield of the irrigated fodder between the two woredas were compared using a t-test. The weight gain of the fattening sheep was analyzed with the General Linear Model procedure of SPSS. The profitability of the fattening trial was assessed by conducting partial budget analysis considering the major variable costs (feed supplements and labour for irrigation) and the returns in terms of body weight gain. The variable costs were considered as similar among sites. The returns from body weight gain were calculated considering both a constant purchasing and selling price of 43 ETB per kg of live weight, and the current market prices at the time of sale of the fattened sheep.

RESULTS

Performance of the oat-vetch irrigated fodder

The biomass yield of irrigated oat-vetch fodder was 5.4±.38 tons DM/ha in Ganna, 5.6±.63 tons DM/ha in Jawe, and 7.2±1.08 tons DM/ha Kerekicho) sites. The yields obtained from Jawe and Ganna plots were similar, whereas that obtained from the Angacha site was higher ($P<0.05$). The variability between individual farmer plots was also considerable, especially in Kerekicho kebele where the performance varied between 6 and 10 tons/ha. The highest biomass yield was recorded from the field of the farmer in Kerekicho who owned the smallest land holding of all participants. As other green fodder was not available during the dry period, protecting the oat-vetch fodder from roaming animals and pests required extra care and close follow up. The mean crude protein content of the oat-vetch mixture at the time of harvest was 16% on a dry matter basis, while the ME content was 10 MJ/kg DM.

Chemical composition of local feed resources used for the sheep fattening

The nutritional value of locally available feed resources used for sheep fattening are shown in Table 1. Comparing the two sites, the diversity of the diet of the fattening sheep was higher in Angacha than in Lemo (19 vs 15). The nutritive value of the feed resources varied considerably. The crude protein concentration of the feeds ranged from 2.3% (in *enset* root) to 24.1% (in *korch* leaf) on a dry matter basis. Twenty five percent of the feeds had >20% CP, while those with a CP concentration of 10-20% constituted 54% of the feeds. On the other hand, 16% of the feeds had CP concentration of less than 7%. The NDF content ranged from 21.7% (in cabbage leaf) to 75.5% (in teff straw), with 75% of the feeds having NDF concentration of less than 65%. The estimated DMD ranged widely from 42% to 82%, with wheat straw showing the lowest and cabbage the highest DMD digestibility. Except the straw feeds (teff straw, barley straw and wheat straw) the DMD values were above 50%, and 63% of the feeds had digestibility of more than 60%. Similarly there was a considerable difference in the estimated ME concentration of the feeds ranging from 5.1 MJ/kg DM (in wheat straw) to 11.6 MJ/kg DM (in *Areke atella*), with about 33% of the available feeds having ME concentration of above 9 MJ/kg DM. The mineral concentrations were in the following ranges (g/kg DM): Ca, 1.6-22; P, 0.9-3.8; Mg, 0.64-3.6; Zn, 0.008-0.0.06; Mn, 0.03-0.67; and Fe, 0.09-1.7 (Table 2).

Performance of fattening sheep and the profitability of the fattening practice

The mean initial weight of the fattening sheep was similar across the three sites, being 30.6±1.15 kg in Jawe, 30.5±1.21 kg in Ganna, and 29.6±0.95 kg in Kerekicho (Fig 2). However, the mean final body weight after about 70 days of fattening varied from 35.0 – 38.3kg/head. The highest mean final body weight was obtained in Kerekicho, and the lowest was in Jawe with the difference between the two sites being significant ($P<0.05$). The mean daily body weight gain per head ranged from 52±7.2g (Jawe) to 106±10.5 g (Kerekicho), and significant ($P<0.05$) effects of site and gender of the household head were observed (Table 2). The profitability of the fattening practice was tested through partial budget analysis, i.e., considering the major variable costs incurred in the fattening (including feed supplements and irrigated fodder) and the returns obtained in terms of body weight gain (Table 3). When the returns were calculated with the assumption of a constant purchasing and selling price per unit of live weight, the balance was marginal in Jawe kebele (3 ETB/head), but considerably positive in Ganna (89 ETB/head) and Kerekicho (171 ETB/head). However, with the current market price at the time of sale, the balance was considerably negative in Jawe (-58 ETB/head), marginal in Ganna (0 ETB/head), but still profitable in Kerekicho (55 ETB/head).

Table 1. Chemical composition, estimated dry matter digestibility (DMD), metabolizable energy (ME) and mineral concentrations of locally available feeds and irrigated oat-vetch fodder used by farmers to fatten sheep in Lemo and Angacha districts

Feed	Site*	OM	CP	NDF	ADF	ADL	DMD	ME	Ca	P	Mg	Fe	Zn	Mn
		% on DM basis					%	MJ/kg DM	g/kg DM			mg/kg DM		
Desho grass *(Pennisetum pedicellatum)*	L&A	91.6	11	64	37	3.2	58	7.9	4.4	3.1	2.1	713	22	99
Desmodium *(Desmodium intortum)*	A	88.1	16	54	44	14	54	7.2	8.6	3.2	2.0	1002	31	85
Enset leaf *(Ensete ventricosum)*	L&A	86.4	13	64	38	13	58.	7.9	5.3	3.5	1.4	93	16	35
Enset root *(Ensete ventricosum)*	L&A	87.7	2.3	67	17	3.7	70	9.9	10	2.6	2.6	1348	36	242
Areke atella (local distillers grains)	A	95.4	21	55	15	5.4	80	11.6	10	3.3	2.6	160	38	106
Avocado leaf *(Persea americana)*	L&A	90.4	11	54	50	30	47	6.0	8.6	2.8	6.5	709	30	121
Bamboo leaf *(Yushania alpine)*	A	81.3	14	52	40	11	57	7.7	12	3.6	4.3	1671	38	201
Banana leaf *(Musa acuminate)*	L&A	81.9	15	59	36	13	60	8.2	12	2.5	3.0	913	30	666
Cabbage leaf *(Brassica oleracea)*	A	91.8	15	22	10	1.6	82	11.0	9.5	2.8	2.7	363	14	399
Carrot leaf *(Daucus carota)*	L	84.1	10	26	22	4.2	70	9.9	2.6	2.3	0.64	455	12	68
Chat leaf *(Khatha edulis)*	L&A	91.7	10	50	31	12	63	8.7	1.6	3.9	2.9	891	49	71
Coffee atella (coffee residue)	A	93.4	12	45	29	9.1	65	9.0	10	2.6	1.1	154	32	149
Grawa leaf *(Veronia amygdalina)*	L&A	87.1	23	52	39	23	61	8.3	2.5	2.5	0.82	707	41	57
Korch leaf (*Erythrina brucei)*	A	86.6	24	45	39	13	62	8.5	12	1.8	3.3	1504	29	184
Maize leaf (*Zea mayes)*	L&A	84.0	13	53	30	3.9	64	8.9	22	2.3	4.2	329	44	69
Natural mixed grass	L&A	83.0	12	38	27	8.6	66	9.3	12	1.7	2.5	299	8.3	753
Potato leaf (*Solanum tuberosum)*	L	85.4	20	39	28	5.6	69	9.7	6.6	1.8	2.6	1033	13	88
Sesbania leaf (*Sesbania sesban)*	L&A	91.4	24	44	36	8.9	64	8.8	18	1.7	4.8	132	33	40
Wanza leaf (*Cordia Africana)*	L&A	84.0	16	65	42	8.4	56	7.5	4.6	1.8	1.1	177	24	305
Teff straw (*Eragrostis tef*)	L&A	91.7	4.7	76	45	5.5	49	6.3	3.1	2.8	1.1	93	62	34
Barley straw (*Hordeum vulgare*)	L&A	93.0	4.0	74	48	5.6	46	5.8	2.8	1.8	1.2	110	45	50
Wheat straw (*Triticum aestivum)*	L&A	87.5	3.2	73	53	14	42	5.1	1.7	0.89	0.85	95	23	36
Oat-vetch fodder**	L&A	94	16	61	27	8	68	10	7.2	3.4	2.2	203	21	97

OM=organic matter; CP=crude protein; NDF=neutral detergent fiber; ADF; acid detergent fiber; ADL=acid detergent lignin; ME -= estimated metabolisable energy; *L&A=Lemo and Angacha; L=Lemo; A=Angacha; **fodder produced by irrigation

Table 2: The mineral status of feed resources used for sheep fattening in Lemo and Angacha districts in relation to ruminant animal requirements

Mineral	Normal range for ruminants g/kg DM*	Percentage of the feed resources that fall		
		Above (%)	Below (%)	Within range (%)
Ca	3.4 – 7.0	54	21	25
P	1.2 – 2.1	63	4	33
Mg	1.0 – 2.0	54	13	33
Mn	0.02 – 0.04	83	0	17
Zn	0.015 – 0.017	75	13	13
Fe	0.06 – 1.00	17	0	83

*Recommended requirements according to NRC (1985, 1996)

Farmers' reflections during focus group discussions

The participant farmers acknowledged that land is their main constraint to produce enough grain and livestock products, and that small-scale irrigation can be a potential alternative to produce more than twice per year and improve their land productivity. During field visits to Angacha district, the farmers learned how irrigation water from shallow wells can be economically used. The farmers in visited areas have been using the irrigation water mainly to raise seedlings of vegetables in their nurseries, which they then transplant to larger plots when the short or main rains approach. In that way they maximize the amount of land they can irrigate. Unmarketable vegetable products have been used as animal feed. Although motor pumps are used by some farmers, the majority use rope and washer pumps, which the visitors appreciated (farmers from Lemo) and preferred to treadle pumps. The farmers noted that growing irrigated fodder during the dry period required extra labour to regularly water the fodder plots and that using rope and washer pumps would reduce their labour demand. They also added that as green fodder was rarely available during the dry period, the irrigated fodder was found vulnerable to animal damage and therefore adequate fencing was found to be necessary.

Reflecting on the fattening trial, the farmers mentioned that although they had some level of experience with sheep rearing, they were overwhelmed by the labour and feed demand of the five yearling Doyogena sheep. Most of the farmers mentioned that the feed consumption of the sheep was considerably higher than the amount they would spend for a fattening bull and that they were challenged to meet the feed demand of the five sheep. Moreover, they noted that a bull can be easily tethered and fed, while five sheep need more labor engagement and regular veterinary treatments. Based on these points (labour and feed demand), the majority of the farmers (65%) indicated their preference to shift to cattle fattening, whereas the other farmers (35%) insisted they still prefer to continue with sheep fattening, but with fewer sheep at one time (2-3 per fattening cycle). The latter groups mentioned the ease with which fattened sheep are marketed and the less risk associated with the fattening (in case of death of animals) as a justification.

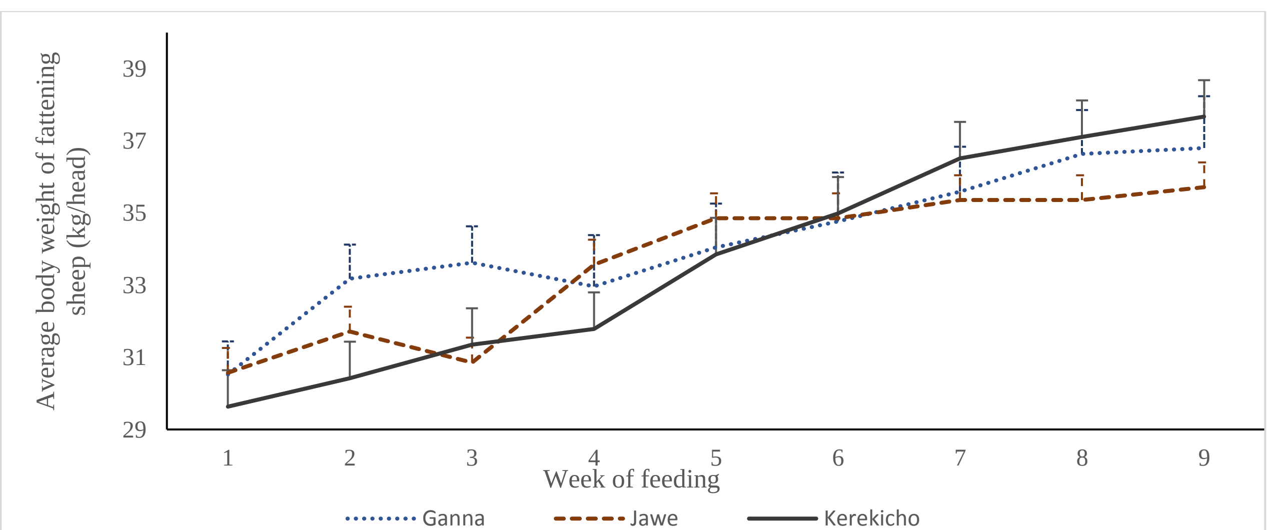

Figure 2. Body weight development of fattening Doyogena sheep by smallholders in southern Ethiopia

Table 3. Weight gain of yearling Doyogena sheep fattened by smallholder farmers using irrigated oat-vetch fodder as a supplement in Lemo and Angacha districts

	Animals (n)	Initial weight (kg)	Final weight (kg)	Weight gain (kg)	Rate of gain (g/day)
Site of fattening					
Jawe	15	30.6	35.0	4.4	52
Ganna	19	30.5	36.9	6.4	70
Kerekicho	34	29.6	38.3	8.3	106
Gender of HH*					
Male headed HH	53	30.0	36.3	6.3	89.8
Female headed HH	15	29.6	38.2	8.6	110
Pooled SEM		1.11	1.23	1.10	4.31
P-values					
Site		0.242	0.023	0.005	0.001
Gender of HH		0.466	0.141	0.201	0.050

*HH=Household

DISCUSSION

Small ruminants are generally considered as immediate sources of cash income for smallholders in the mixed farming system of the Ethiopian highlands (Kocho *et al.,* 2011). Farmers usually cover important household expenditures from sale of animals. Building on the existing practices and enabling farmers to engage with market oriented intensive fattening is one route to diversification of income and livelihood. As feed is the main input in a fattening operation and availability of good quality forage is a major constraint in the dry periods, this study experimented with the possibility of integrating irrigated fodder production and sheep fattening as a means to increase the income of farmers.

Performance of irrigated oat-vetch fodder in relation to water lifting pumps

Under good management and in suitable areas the fodder yield of oat-vetch mixture is reported to be between 8-12 tons DM/ha (Mengistu, 2006; Alemu *et al*., 2007), which appears to be higher than the biomass yield (5-7 tons/ha) recorded in the present experiment. Moisture stresses and soil nutrient levels might have influenced the yield performance in the present trial. Moreover, some of the fodder plots, especially in Ganna kebele, were partly grazed by animals due to weak fencing and poor management at the start of the fodder growing period. Availability of surface water for irrigation in the form of river/stream and ponds in the research area is limited to few places located to the lower bottom of the watersheds. Those farmers who have access to stream water for irrigation have developed their own bylaws to use the resource orderly with technical support from the district irrigation experts. However, for the majority of the farmers in the area, ground water from shallow wells is the main source of water to engage in small-scale irrigation. In this study, the farmers used two types of pumps to extract water for the fodder production: rope and washer pumps in Angacha; treadle pumps in Lemo. The biomass yield difference between the two sites can be partly explained by the efficiency of pump types used. In Angacha, although the ground water table was relatively deep (15-18m), it was observed that the rope and washer pumps made it easier to extract water from the wells and irrigate the fodder plots. On the other hand the treadle pumps that the Lemo farmers used were less efficient in extracting water from the wells at a depth of 8-12m, which forced the farmers to resort to using buckets to pull water. Previous comparative evaluations have also shown that rope and washer pumps exceed other hand pumps in efficiency to lift water from underground (Harvey and Drouin, 2006). During experience sharing visits, Lemo farmers showed strong interest to acquire rope and washer pumps for future small-scale irrigation practices. These pumps are permanently fixed with cement on the mouth of the wells, a feature that farmers valued as an added advantage to reduce theft. On the other hand treadle pumps have been reported to be effective in pumping surface water (stream, pond and canal) from a depth of 1-2 m (Lambert and Faulkner, 1991; Chigerwe *et al.,* 2004; Namara *et al.,* 2014). As the majority of the farmers in the study area do rely on shallow wells, a better option to catalyze small-scale irrigation thus appears to be rope and washer pumps.

The farmers in Angacha have been producing different vegetables using irrigation for several years supported by local NGO initiatives. That prior skill seems to have helped them to adopt a better management practice with the irrigated fodder. In this regard different research findings indicate that prior exposure to practices that are related to a newly-introduced technology positively influence the rate of adoption (Marenya and Barrett, 2007; Noltze *et al.,* 2012). The seedbed preparations, planting, irrigation, and weeding practices were visibly better in Angacha than in Lemo.

In addition to the skill, the farmers have acquired awareness about the importance of small- scale irrigation in improving the income of households. During field visits in Angacha, it was observed that the farmers have been successfully producing and marketing vegetables, mainly cabbage and carrot to markets ranging from the surrounding towns to as far as 240 km from Angacha. From this observation it can be inferred that research and development engagements that improve the knowledge, skills and exposure of farmers have an important carry over effect for further related development interventions.

The feed resource base and the quality of available feeds in the study sites

From the inventory of feed resources used for sheep fattening in the present study, it is apparent that farmers try to diversify the diet of their animals using a range of plant materials and household refusals. The diversity appears desirable because as the number of dietary components increases, there is a chance that the deficiency of one dietary component (in terms of energy and nutrients) is compensated by others making the diet more balanced (Beck and Peek, 2005; Fraser *et al.*, 2013). These benefits can be achieved if the different dietary components are mixed together in a defined manner and fed simultaneously (Provenza *et al.*, 2009). Providing practical training on how to optimize the diet of fattening animals using the available feed resources may be important to address knowledge gaps in the study area.

Table 4. Costs and returns of yearling male Doyogena sheep fattened by farmers in Lemo and Angacha using irrigated oat-vetch fodder as a supplement

Records	Quantity $^{\varphi}$	Unit value (ETB)	Total value (ETB)
Feed supplements per animal			
Wheat bran (kg)	12	1.8	21.6
Noug Cake (kg)	4	3.5	14
Salt (kg)	0.6	10	6
Fodder production costs per animal			
Seed (kg)	0.15	22.5	5.4
Fertilizer (kg)	0.5	1.5	0.8
Irrigated fodder-labor (Man-day/animal)$^{\gamma}$	2	70	140
Gross costs			186
Returns from weight gain per animal under two price scenarios*			
Jawe	4.4	43	189
		29	128
Ganna	6.4	43	275
		29	186
Kerekicho	8.3	43	357
		29	241

$^{\varphi}$kg or days;
$^{\gamma}$Labor demand for irrigated fodder plot management (an hour per day for 2 months);
*two price scenarios for fattened animals were used: 1) constant purchasing and selling price of 43 ETB/ kg LW, and 2) current market price at the time of sale of 29 ETB/kg LW

Nitrogen is an important limiting nutrient for livestock production (Gerber *et al.*, 2014; Dillard *et al.*, 2015). In the present analysis, about 84% of the feeds had CP concentration of above 7%, which is considered as the minimum level required for normal rumen function (Van Soest, 1994). About 41% of the feeds had CP concentration of above 15%, which is considered as sufficient for optimum growth and lactation (Poppi and McLennan, 1995). On the other hand the crop residues, which constitute the bulk of the DM in the diet of animals in the study area have a CP concentration (3-4.8%) much lower than the minimum requirement for normal rumen functioning. Increasing the dietary contribution of other fodder plants in the ration of fattening animals is therefore very important. In this regard, in addition to the irrigated fodder supplement, the value of the leaves of indigenous trees such as *Veronia amygdalina* (Grawa leaf: CP 22.8%), *Erythrina brucei* (Korch leaf: CP: 24.1%), and *Cordia africana* (Wanza leaf: CP: 15.8%) needs due attention, as they have favorable CP concentrations comparable to cultivated fodders. These indigenous trees are grown for multiple purposes serving as a source of fuel and herbal extracts for ethno-veterinary practices as well as providing barriers against wind and intruders. Taking the mean CP concentrations of these fodder trees and crop residues, the mixing ratio (fodder leaf: crop residue) that enables to meet the minimum CP concentration in the ruminant would be 1:4.5, while that which allows optimum growth would be around 1:1 on dry matter basis.

The level of the cell wall fraction (NDF) in tropical forages beyond which the dry matter intake of animals is negatively affected is considered to be around 65% (Van Soest *et al.,* 1991). In the present study, about 75% of the feeds which were used for the sheep fattening had NDF concentration of less than 65%, showing a broadly acceptable fiber concentration. However, similar to the CP concentration, the cereal straws contained NDF concentration higher than the threshold mentioned above. The 1:1 mixing ratio between crop residues and fodder leaves can reduce the fiber concentration to a level that would not negatively affect dry matter intake. In terms of energy, about one third of the feeds were estimated to contain ME above 9 MJ ME/kg DM, which is comparable to a good quality forage, and another third of the feeds recorded values of 8-9MJ ME/kg DM, which is comparable to moderate quality hay under tropical conditions (Leng, 1990). With regard to minerals analyzed, the majority of the feeds showed adequate or more than adequate concentrations for ruminant production (NRC, 1985, 1996). However, deficiencies were observed in 21% of the feeds for Ca, 4% of the feeds for P, 13% of the feeds for Mg and 13% of the feeds for Zn (Table 2). Wheat straw was the least in terms of its potential to provide macro and micro minerals requirements for ruminants. The result therefore signifies the importance of mixing straw basal diets with different feed resources while feeding to fulfill not only energy and protein demands, but also mineral requirements for normal growth and reproduction.

Sheep fattening performance

The average daily body weight gain (52-110 g/d) observed in the present trial was generally within the range reported by other researchers for the Doyogena sheep breed (Hassen *et al.*, 2002; Manaye *et al.*, 2009), but higher than the weight gain performance of small breeds (Menze) reported from on-station evaluation trials (20-50g/d/h) (Mukasa-Mugerwa *et al.,* 2000; Melaku *et al.*, 2004). The significant difference in the average daily weight gain between sites in the present study could be mainly attributed to differences in the feeding management of the animals. The performance of the oat-vetch fodder and the diversity of locally available feeds were better in Angacha than Lemo (Figure 1, Table 1). Farmers in Angacha have also an established practice of producing vegetables through irrigation, which also served as an additional source of green feed in the form of cabbage (15.3% CP; 11.0 MJ ME/kg DM) and carrot leaves to fattening animals (Table 1). Farmers in female headed households managed the fattening animals in a better manner than male headed households, as can be seen from the rate of weight gain between the two gender groups (Table 3). Females mostly stay around the homestead, and this might have helped the participant women to give more time managing their fattening animals. Moreover, these women were involved in producing local alcoholic beverage (*areke*) as a source of income, and the distillers grains (20.6% CP; 11.6 MJ ME/kg DM) were fed to the fattening sheep (Table 1) which is a good source of energy and protein for the animals.

Although the intake of the sheep from the basal diet was not measured in the present study due to the nature of the experiment, it appears that, for some of the experimental animals, the intake from the basal diet was not sufficient to meet the daily maintenance requirements. This is because the calculated ME intake from the known fodder and concentrate supplements (ca 3.78 MJ/day/head) would enable the animals to gain about 125 g/day/head if it were used only for body weight gain (NRC, 1985), which is considerably higher than the observed daily body weight gain. It is thus likely that some of the animals, particularly those in the lower range of daily weight gain, might have used part of the energy intake from the supplement to fulfill their maintenance requirements which were not covered due to a possible low basal diet intake. This agrees with the farmers' feedback about the limited feed resource they have had to fatten five sheep at a time.

Taking into account requirements for space, feed resources and capital, small ruminant fattening is often considered a better option than large ruminants for resource poor farmers (Udo *et al.,* 2011). During the group discussion held with the farmers towards the end of the fattening, the majority of the farmers characterized the sheep fattening as feed and labour intensive and wanted to shift to cattle fattening, noting that a fattening bull appears to be less labor and feed demanding than five sheep, and yet both have a comparable profit margin. While the farmers point on the labour demand was easily understandable, their point on feed consumption was unexpected. This may be partly due to the fact that the maintenance requirement of sheep are higher per unit of body weight as maintenance requirement scales with metabolic body weight and larger animals thus have relatively lower maintenance energy requirements (McDonald *et al.,* 2010).

However, some of the farmers still preferred sheep fattening, because they believed sheep fattening to be less risky compared to cattle fattening. They mentioned that if a fattening bull dies of illness, the loss will be hundred percent whereas in case of sheep, even if there are incidences of death, the damage may not result in total loss. These groups of farmers preferred to fatten lower numbers of sheep at a time (about 2-3 rather than 5) in order to properly address labor and feed related issues. Generally the farmers showed differences in their preferences for fattening animals, and they had their own plausible reasons for their decisions. To make future interventions effective, it is thus important to understand the preferences of the farmers and cluster them according to their choices.

Different reports on the performance of indigenous breeds indicate that supplementation of fattening sheep with locally available protein and energy sources can be economically feasible and bring additional income to the farmers (Gebremariam *et al.,* 2006; Kocho *et al.,* 2011; Ermias *et al.,* 2013). In the present trial, the comparison between major variable costs (feed and labor) and returns from live weight gain also shows that, with good feeding management, sheep fattening can have a potential to generate additional income to smallholder farmers in the study area. However, its potential to generate additional income was highly dependent on the purchasing and selling price of sheep. The price of sheep at the time of purchasing (around March/May, 2014) was about 43 ETB/kg live weight, but when the farmers brought their fattened sheep to the market (August, 2014), the price had dropped to about 29 ETB/kg live weight, negatively affecting the return both from price spread and feeding margin. Seasonal and inter-market price fluctuation appear to be inherent characteristics of the sheep market in Ethiopia (Solomon *et al*., 2003; Kocho *et al.,* 2011; Tarawali *et al.*, 2011) and developing a system where farmers can get adequate market information is essential to the profitability of the fattening practices. An important lesson from this trial is to carefully adjust the timing of the fattening so that the farmers can strike the markets for fattened sheep when the supply is expected to be low and the prices are high, which usually occur in the dry periods. Irrigated fodder production has an important role in achieving that target by supplying green fodder at the time when feed quality and quantity are major limitations.

CONCLUSION

The irrigated oat-vetch fodder provided good quality green feed supplement to the basal diet of the fattening sheep. In addition to the irrigated fodder, the study revealed that there are indigenous tree leaves which have a good potential to serve as a supplement and enhance the feeding value of crop residues. Increasing the availability and utilization of such indigenous fodder sources could reduce the cost of production of cultivated fodders. The performance of the fattening sheep in terms of daily body weight gain was within acceptable ranges and the fattening practice showed that, although the practice has a potential to generate additional income to the farmers, the return is highly dependent on market prices. Market information with regard to the timing of buying (animals to be fattened) and selling (finished animals) is critical for the profitability of the fattening, as there are marked seasonal and inter-market differences in the price of sheep. Contrary to our assumption, the feedback from the majority of the farmers revealed that fattening of five sheep at a time was more labor and feed demanding than that of a bull.

Acknowledgement

The authors acknowledge experts and development agents from Lemo and Angacha woreda office of agriculture, as well as Africa RISING project site coordinators, Mr Workneh Dubale and Fekadu Tessema, for their valuable support and follow-up during the course of the trial. This research was financed by Africa RISING and Innovation Lab for Small-Scale Irrigation projects, both of which are part of the US Government's Feed the Future initiative.

Conflict of interest statement

The authors declare that they have no conflict of interest.

REFERENCES

Abegaz, A., van Keulen, H. and Oosting, S.J. 2007. Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. Agricultural Systems, 94:391-404.

Alemu, B., Melaku, S., Prasad, N.K. 2007. Effects of varying seed proportions and harvesting stages on biological compatibility and forage yield of oats (Avena sativa L.) and vetch (Vicia villosa R.) mixtures. Livestock Research for Rural Development, 19:60-67.

AOAC. 1990. Official Methods of Analysis. Association of Official Analytical Chemists, Arlington, VA.

Beck, J.L. and Peek, J.M. 2005. Diet composition, forage selection, and potential for forage competition among elk, deer, and livestock on Aspen–Sagebrush summer range.

Rangeland Ecology and Management 58:135-47.

Bezabih, M., Pellikaan, W.F., Tolera, A., Khan, N.A. and Hendriks, W.H. 2014. Nutritional status of cattle grazing natural pasture in the Mid Rift Valley grasslands of Ethiopia measured using plant cuticular hydrocarbons and their isotope enrichment. Livestock Science, 161:41-52.

Chigerwe, J., Manjengwa, N., van der Zaag, P., Zhakata, W. and Rockström, J. 2004. Low head drip irrigation kits and treadle pumps for smallholder farmers in Zimbabwe: a technical evaluation based on laboratory tests. Physics and Chemistry of the Earth, Parts A/B/C, 29:1049-59.

Desta, Z.H. and Oba, G. 2004. Feed scarcity and livestock mortality in enset farming systems in the Bale highlands of southern Ethiopia. Outlook on Agriculture, 33:277-80.

Dillard, S.L., Wood, C.W., Wood, B.H., Feng, Y., Owsley, W.F. and Muntifering, R.B. 2015. Effects of nitrogen fertilization on soil nutrient concentration and phosphatase activity and forage nutrient uptake from a grazed pasture system. Journal of Environmental Management, 154:208-15.

ELMIS. 2015. Ethiopian Livestock Market Information System: Market trends. http://www.lmiset.net/Pages/Public/Chart.aspx?&selectedTab=0&selectedMenuId=0&menuState= accessed on 20 June, 2015.

Ermias, T., Solomon, M. and Mengistu, U. 2013. The effect of barley bran, linseed meal and their mixes supplementation on the performances, carcass characteristics and economic return of Arsi-Bale sheep. Small Ruminant Research, 114:35-40.

Fraser, M.D., Vale, J.E. and Dhanoa, M.S. 2013. Alternative upland grazing systems: Impacts on livestock performance and sward characteristics. Agriculture, Ecosystems and Environment, 175:8-20.

Freer, M., Moore, A.D. and Donnelly, J.R. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems, 54:77-126.

Gebregziabher, G., Namara, R.E. and Holden, S. 2009. Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. Agricultural Water Management, 96:1837-43.

Gebremariam, T., Melaku, S. and Yami, A. 2006. Effect of different levels of cactus (*Opuntia ficus-indica*) inclusion on feed intake, digestibility and body weight gain in tef (*Eragrostis tef*) straw-based feeding of sheep. Animal Feed Science and Technology, 131:43-52.

Gerber, P.J., Uwizeye, A., Schulte, R.P.O., Opio, C.I. and de Boer, I.J.M. 2014. Nutrient use efficiency: a valuable approach to benchmark the sustainability of nutrient use in global livestock production? Current Opinion in Environmental Sustainability, 9–10:122-30.

Getnet, M., Hengsdijk, H. and van Ittersum, M. 2014. Disentangling the impacts of climate change, land use change and irrigation on the Central Rift Valley water system of Ethiopia. Agricultural Water Management, 137:104-15.

Gizachew, L. and Smit, G.N. 2005. Crude protein and mineral composition of major crop residues and supplemental feeds produced on Vertisols of the Ethiopian highland. Animal Feed Science and Technology, 119:143-53.

Gizaw, S., Lemma, W., Beneberu, T., Shenkute, G., Wamatu, J., Thorpe, W. and Duncan, A.J. 2012. Characterization of the farming and livestock production systems and the potentials to enhance productivity through improved feeding in the Subalpine Highlands of Amhara region, Ethiopia. International Livestock research Institute. https://cgspace.cgiar.org/handle/10568/24732.

Hagos, F. and Mamo, K. 2014. Financial viability of groundwater irrigation and its impact on livelihoods of smallholder farmers: The case of eastern Ethiopia. Water Resources and Economics, 7:55-65.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T. and Descheemaeker, K. 2009. Livestock water productivity in mixed crop–livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. Agricultural Systems, 102:33-40.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D. and Lesschen, J.P. 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems and Environment, 108:1-16.

Harvey, P.A. and Drouin, T. 2006. The case for the rope-pump in Africa: A comparative performance analysis. Journal of Water and Health, 4:499-510.

Hassen, Y., Sölkner, J., Gizaw, S. and Baumung, R. 2002. Performance of crossbred and indigenous sheep under village conditions in the cool highlands of central-northern Ethiopia: growth, birth and body weights. Small Ruminant Research, 43:195-202.

Kocho, T., Abebe G., Tegegne, A. and Gebremedhin, B. 2011. Marketing value-chain of smallholder sheep and goats in crop-livestock mixed farming system of Alaba, Southern Ethiopia. Small Ruminant Research, 96:101-5.

Lambert, R.A. and Faulkner, R.D. 1991. The efficient use of human energy for micro-scale irrigation. Journal of Agricultural Engineering Research, 48:171-83.

Leng, R.A. 1990. Factors affecting the utilization of 'poor-quality' forages by ruminants particularly under tropical conditions. Nutrition Research Reviews, 3:277-303.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. and Wilkinson, R.G. 2010. Animal Nutrition. 7th edition. Ashford colour press ltd, Gosport.

Manaye, T., Tolera, A. and Zewdu ,T. 2009. Feed intake, digestibility and body weight gain of sheep fed Napier grass mixed with different levels of Sesbania sesban. Livestock Science, 122:24-9.

Marenya, P.P. and Barrett, C.B. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. Food Policy, 32:515-36.

Mekasha, A., Gerard, B., Tesfaye, K., Nigatu, L. and Duncan, A.J. 2014. Inter-connection between land use/land cover change and herders'/farmers' livestock feed resource management strategies: a case study from three Ethiopian eco-environments. Agriculture, Ecosystems and Environment, 188:150-62.

Mekonnen, A., Tessema, F., Mulugeta, M., Mengistu, S., Wolde, S. and Abiso, T. 2014. Characterization of the farming and livestock production systems and the potentials to enhance productivity through improved feeding in Lemo district, Ethiopia. International Livestock Research Institute. https://cgspace.cgiar.org/handle/10568/51610.

Melaku, S., Peters, K.J. and Tegegne, A. 2004. Effects of supplementation with foliages of selected multipurpose trees, their mixtures or wheat bran on feed intake, plasma enzyme activities, live weight and scrotal circumference gains in Menz sheep. Livestock Production Science, 89:253-64.

Mengistu, A. 2006. Country pasture/forage resources of Ethiopia. FAO. http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Ethiopia-English.pdf

Mukasa-Mugerwa, E., Lahlou-Kassi, A., Anindo, D., Rege, J.E.O., Tembely, S., Tibbo, M. and Baker, R.L. 2000. Between and within breed variation in lamb survival and the risk factors associated with major causes of mortality in indigenous Horro and Menz sheep in Ethiopia. Small Ruminant Research, 37:1-12.

Namara, R.E., Hope, L., Sarpong, E.O., De Fraiture, C. and Owusu, D. 2014. Adoption patterns and constraints pertaining to small-scale water lifting technologies in Ghana. Agricultural Water Management, 131:194-203.

Noltze, M., Schwarze, S. and Qaim, M. 2012. Understanding the adoption of system technologies in smallholder agriculture: The system of rice intensification in Timor Leste. Agricultural Systems, 108:64-73.

NRC. 1985. Nutrient Requirements of Sheep. National Research Council, National Academic Press, Washington, USA.

NRC. 1996. Nutrient Requirements of Beef Cattle. National Research Council, National Academy Press, Washington DC.

Oddy, V.H., Robards, G.E. and Low, S.G. 1983. Prediction of in vivo digestibility of ruminant feeds from fibre and nitrogen content. In: Proceedings of the 2nd international conference of international network of feeds information centers, pp. 395-8.

Oosting, S.J., Mekoya, A., Fernandez-Rivera, S. and van der Zijpp, A.J. 2011. *Sesbania sesban* as a fodder tree in Ethiopian livestock farming systems: Feeding practices and farmers' perception of feeding effects on sheep performance. Livestock Science, 139:135-41.

Poppi, D.P. and McLennan, S.R. 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science, 73:278-90.

Provenza, F.D., Villalba, J.J., Wiedmeier, R.W., Lyman, T., Owens, J., Lisonbee, L., Clemensen, A., Welch, K.D., Gardner, D.R. and Lee, S.T. 2009. Value of plant diversity for diet mixing and sequencing in herbivores. Rangelands, 31:45-9.

Solomon, A., Workalemahu, A., Jabbar, M.A., Ahmed, M.M., and Hurissa, B. 2003. Livestock marketing in Ethiopia: A review of structure, performance and development initiatives. In: Socio-economics and Policy Research Working Paper 52 (ed. by M.A. Jabbar and S.E. Benin). International Livestock Research Institute.

Tarawali, S., Herrero, M., Descheemaeker, K., Grings, E. and Blümmel, M. 2011. Pathways for sustainable development of mixed crop livestock systems: Taking a livestock and pro-poor approach. Livestock Science, 139:11-21.

Tsegahun, A., Chairatanayuth, P., Vijchulata, P. and Tadsri, S. 2006. The effect of dry season supplementation of Lotus corniculatus hay on body and fleece weights of three sheep breeds grazing natural pasture under Ethiopian conditions. Kasetsart Journal - Natural Science, 40:978-86.

Udo, H.M.J., Aklilu, H.A., Phong, L.T., Bosma, R.H., Budisatria, I.G.S., Patil, B.R., Samdup, T. and Bebe, B.O. 2011. Impact of intensification of different types of livestock production in smallholder crop-livestock systems. Livestock Science, 139:22-9.

Van Soest, P.J. 1994. Nutritional Ecology of Ruminants. Cornell University Press, Ithaca, NY.

Van Soest, P.J., Roberton, J.B. and Lewis, B.A. 1991. Methods for dietary fibre, neutral detergent fibre and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science, 74:3583-97.

Worqlul, A.W., Collick, A.S., Rossiter, D.G., Langan, S. and Steenhuis, T.S. 2015. Assessment of surface water irrigation potential in the Ethiopian highlands: The Lake Tana Basin. CATENA, 129:76-85.

Yayneshet, T., Eik, L.O. and Moe, S.R. 2008. Feeding Acacia etbaica and Dichrostachys cinerea fruits to smallholder goats in northern Ethiopia improves their performance during the dry season. Livestock Science, 119:31-41.