

# Characterisation of smallholder dairy production systems using animal welfare and milk quality

Bettie S. Kawonga · Mizeck G. G. Chagunda ·  
Timothy N. Gondwe · Sera R. Gondwe ·  
James W. Banda

Accepted: 15 January 2012 / Published online: 31 January 2012  
© Springer Science+Business Media B.V. 2012

**Abstract** The aim of the current study was to characterise and evaluate production system of smallholder dairy farmers using an index based on combined score of animal welfare and milk quality. Farms were grouped into three categories, tier 1, tier 2 and tier 3. To test the robustness of the characterisation, milk yield (MY), calving interval (CI) and body condition scores (BCS) were used. In the study area, the majority (66.3%) of smallholder dairy farmers practiced cut-and-carry as compared to 15.3% who grazed their cows. The rest combined cut-and-carry and grazing. Cows of farmers in tier 1 had the lowest mean MY (5.4 kg/day, SE=0.4), lowest mean BCS (2.1 kg/day, SE=0.09) and longest mean CI (603 days, SE=27) than farmers in tier 3, mean MY (10.8 kg/day, SE=0.6), mean BCS (2.6, SE=0.06) and mean CI (404 days, SE=17). The study demonstrated that a simple and yet novel method based on farm level indicators can be developed and could assist to timely identify specific problems on the farm.

**Keywords** Smallholder dairy production system · Animal welfare · Milk quality

## Introduction

Milk is rich in essential nutrients and its availability would directly contribute to food and nutritional security, and poverty reduction. Promoting the growth of smallholder dairy production would not only contribute to increased household income but would also provide a robust coping strategy where agro-ecological conditions and access to markets provide a favourable environment for dairy production. Smallholder dairy sector has a multiplier effect that would significantly contribute to accelerating growth of the rural economy (Malawi Government 1996). Falvey and Chantanthalaka (1999) indicated that the vast majority of smallholder farmers in the tropics use low input production systems and productivity per cow (milk yield/cow/day) is relatively low. In these systems, animals are fed on crop residues, agro-industrial by-products and roadside grass which are relatively low in protein and digestibility. On these feed resources, productivity is low, animals reach puberty at a late age (often more than 24 months) and calving interval is long (often 18–24 months) (Ibrahim et al. 2011; Falvey and Chantanthalaka 1999).

Herd management practices in nutrition, milking procedure, sanitation and housing play major roles in predisposing the individual animals to diseases (Wanapat and Chanthakhoun 2011; Falvey and Chantanthalaka 1999). Msiska (2003) reported that health-related problems seem to be one of the greatest problems faced by Malawian dairy farmers. Land O'Lakes (2005) indicated that up to 60% milk yield differences exist among dairy animals due to feeds. Hence, improved herd management combined with a veterinary program can be most

---

As we were finalising this manuscript, the project team lost a trusted teacher who was a colleague and a colleague who was our teacher. Professor James W. Banda departed from our midst. "Hamba Kahle James! You taught and you mentored and you guided. Rest in His Peace; rest James, rest."

---

B. S. Kawonga · T. N. Gondwe · J. W. Banda  
Animal Science Department, Bunda College of Agriculture,  
University of Malawi,  
P.O. Box 219, Lilongwe, Malawi

M. G. G. Chagunda (✉)  
Sustainable Livestock Systems Group, SAC Research,  
King's Buildings, West Mains Road,  
Edinburgh, EH9 3JG, Scotland, UK  
e-mail: mizeck.chagunda@sac.ac.uk

S. R. Gondwe  
Agribusiness Management Department,  
Bunda College of Agriculture, University of Malawi,  
P.O. Box 219, Lilongwe, Malawi

effective in optimising production and profitability through prevention of diseases. With increased demand for dairy products and high population pressure (Delgado et al. 2001), the continuing importance of the dairy sub-sector in the Malawian economy depends on productivity increases through breeding programmes and more efficient management practices.

Smallholder dairy farms are not a homogenous group (Mwale 1999). For different purposes, smallholder farms have been classified and categorised using different classification methods. For example, classification based on the level of input and output, land holding size and herd size (Olafadehan and Adewumi 2010; Falvey and Chantanthalaka 1999; Mwale 1999). Although these methods serve well in different situations, simple methods which could be applied in situations of limited data availability are sparse. Such a simple method could be used to assist farmers identify specific problems on the farm and hence help target appropriate interventions.

The use of direct, animal-based measurements to assess the welfare of farm animals is widely used. Scoring systems in dairy cattle have been developed to assess lameness (Manson and Leaver 1989), claw length and cleanliness (Cook 2007), body condition (Wildman et al. 1982), hock and knee lesions (Rutherford et al. 2008), animal behaviour (Gibbons et al. 2009) and other direct animal health and welfare changes (Gibbons et al. 2010). Animal-based systems of classification have the advantages of describing relevant and significant aspects of what matters from the point of view of the animals, express change over time, are capable of being influenced by decisions taken by the individual farmer and can be measurable in a relatively cheap and easy manner (Sørensen et al. 2001). The current study aimed at exploring the application of a classification methodology based on animal welfare and milk quality to describe smallholder dairy production systems in central Malawi.

## Materials and methods

### Study area and data collection

The study was conducted through a baseline survey followed by a 150-day (February to June 2010) observatory period. During the observatory period, no intervention to the farmers' normal management procedures was introduced. This was done in four milk bulking groups (MBG) of Lilongwe milk shed area in the central region of Malawi. There are a total of 18 MBGs and about 1,500 smallholder dairy farmers in Lilongwe milk shed area. During the study, the area received an average of 850 mm of rainfall between November 2009 and April 2010.

For the baseline survey, farmers were randomly selected. However, for the observatory part of the study, choice of

farmers was based on willingness to participate in the performance recording, ownership of a lactating cow and membership to MBG. During the baseline survey, data on household demography, production levels, milk quality (number of times milk was rejected from February to June 2009), health and fertility were collected. Data were obtained from 98 cows comprising of Holstein Friesian (84) and Jersey cows (14). During the study, it was noted that farmers practiced two feeding systems: (1) cows grazed during the day for about 8 h and housed during the night; (2) cows were stall-fed (cut-and-carry). Cows in both systems had access to some concentrates (maize bran, dairy mash) during morning and evening milking. The cows were milked twice in a day, morning and late in the afternoon. Farms followed a standard procedure of teat cleaning using warm water before milking.

### Data collection

Based on results of the baseline survey, farmers were clustered into three groups based on welfare and milk quality. An animal welfare system based on a visual hygiene score of 1 to 10 (Gibbons et al. 2010) was used. The animal welfare system used direct observation of health (cleanliness) in cattle (Cook 2007) and audit of the khola (presence of shade and lying areas) (Gibbons et al. 2010). Cleanliness (presence of manure) was categorised as (1) clean (no presence of manure), (2) lightly soiled (minor splashing), (3) soiled (plaques of manure), (4) heavily soiled (confluent plaques of manure). When a farmer delivers milk at the MBG, the milk is subjected to three milk quality tests, i.e. alcohol test, specific density test and visual/organoleptic test. Milk that does not pass any one of the three tests is rejected. As such, in the current study, the rate of milk rejections was used as an indicator of milk quality.

Farms were scored once every month by the same researcher during monthly farm visits using the same protocol. An index based on the combined score of welfare and milk quality generated the final score for each farm. In the index, the welfare score had a weight of 30% and milk quality score had a weight of 70%. The welfare had a lower weighting than milk yield because of the subjective nature of visual hygiene-scoring. The index score ranged from 0 to 1 with 0 being the lowest and 1 the highest score. At the end of 5 months, farms with an aggregate score between 0.6 and 1 were categorised as tier 3 farms, farms with a final score above 0.4 but below 0.6 were categorised as tier 2 farms and farms with a final score from 0 to 0.4 were categorised as tier 1 farmers. This approach allowed the description and evaluation of production system and characteristics of smallholder dairying in central region of Malawi. During the observatory study, farmers were given recording sheets for recording daily milk yields, service dates and method of service and milk rejection dates. The number of times milk

was rejected at MBG and amount rejected was recorded by farmers and verified at MBG by the researcher during monthly visits. Data collected during observatory study included animal identification number or name, its pedigree and past history (parity, days in milk, calving history), service dates, expected dates of calving and drying, and feeding systems. During each monthly visit, the researcher scored the body condition of the cows as well as the visual hygiene of the animals and the farm. Body condition score was done using a 1–5 (with 0.25 interval) visual and handling condition scoring system (Wildman et al. 1982). Body condition scores of dairy cows of 1.0 represented an emaciated cow and 5 an obese cow. Due consideration of the breed of the cow was taken during body condition scoring.

#### Evaluation criteria

To test the robustness of the characterisation method, three different traits were used. The traits were, milk yield, body condition score and calving interval. Milk, being the principal product of a dairy farm, was chosen to represent production performance. Body condition score represented the cows' body energy status while calving interval represented the cows' fertility. Following is a description of the traits.

The graphical representation of milk yield against time is a lactation curve. The curve is a summary of the pattern of milk yield determined by the biological efficiency of the cow. Lactation curves are valuable tools for dairy farmer for management decision-making and selection (Hanigan et al. 2007). The slope of the curve indicates to the dairy farmer the needed changes in feed management; for example, a rising portion of the curve indicates that cows should be given a higher plane of nutrition, and a declining portion of the curve indicates a lower plane of nutrition. Based on individual production (Gipson and Grossman 1990), a dairy farmer can make management decision early. In contrasting the feeding and management systems, it has been shown that groups of cows of equivalent genotype have different levels of milk production (Anon 1996). Thus, it would be reasonable to expect that lactation curves of cows of two different production systems would also vary as to levels of production and peak yield.

Body condition score is an indicator of the amount of observable fat on the cow. This, in turn, is an indication of

how much energy the cow has stored away for future use (Roche et al. 2009). Although this is a useful piece of information on its own, it is the change in body condition that is important for dairy cow management. Thus, animals should be condition scored periodically and the conservative scores on a particular cow compared. Changes in condition score are the outcome of a positive or negative energy balance (Roche et al. 2009; Waltner et al. 1993). If the cow takes in more energy than is expended, then the cow is in positive energy balance and accumulates body fat. If the cow expends more energy than is available from feed intake, then the cow contributes body fat to make up the deficit. This is termed negative energy balance. The most common application for condition scoring is monitoring the effects of nutrition on the animal. However, condition score is not only indicative of the nutritional status of the animal but can also be a useful guide to both fertility and feed efficiency (Stockdale 2001). Any farming action that results in observable changes in body condition score is a critical feature of that production system.

Calving interval is the period taken before a cow gives birth to a consecutive calf. The practical minimum that most dairy farmers aim for is to have a calf after every calendar year (Falvey and Chantanthalaka 1999). As a reproduction trait, calving interval indicates the ability of a herd to sustain itself through high replacement rates.

#### Statistical analysis

Descriptive statistics were used to characterise smallholder dairy production in central region of Malawi. Analysis of variance was carried out in order to determine the effect of farmer management systems on milk yield, calving interval and body condition score. The following model was used applying the general linear model (GLM) procedure of SAS (SAS 1999). Least square means were used to generate the lactation curves for milk yield and body condition score for each of the three farm categories.

$$Y_{ijkl} = \mu + FM_i + G_j + P_k + ADIM_l + E_{ijkl}$$

Where:

$Y_{ijkl}$  observed average milk yield, body condition score and calving interval

**Table 1** Challenges reported by smallholder dairy farms under different farm management systems in Malawi

FMS	n	Challenges (percentage)					
		Diseases	Feed scarcity	Low milk prices	Lack of extension services	High feed prices	Poor AI services
Tier 1	29	13.3	6.1	8.2	2	0	0
Tier 2	39	12.2	8.2	8.2	6.1	3.1	2
Tier 3	30	10.2	2	2	7.1	5.1	4.1

n total number of farmers, FMS farmer management system

$\mu$	overall mean
$FM_i$	the fixed effect of farmer management system with $i$ =tier 1, tier 2, tier 3
$G_j$	the fixed effect of breed with $j$ =Holstein Friesian, Jersey
$P_k$	the fixed effect of parity with $k$ =1, 2, 3, 4
$ADIM_l$	the fixed effect of days in milk with $l$ =1, 2, ..., 420
$E_{ijkl}$	random effect of the residuals with $\varepsilon$ distributed as $N(0, \delta^2 e)$

## Results

Descriptions of smallholder dairy farmers based on the baseline survey showed that there were more male dairy farmers (71.4%) than female farmers (28.6%) in Lilongwe milk shed area. A high proportion of dairy farmers were over 30 years of age (81.6%) compared to those that were less than 30 years of age (18.4%). Majority of dairy farmers had practiced dairy farming for less than 5 years (54.1%). The majority (85.7%) of smallholder dairy farmers kept cows that were either Holstein Friesians or Holstein Friesian  $\times$  Malawi Zebu crosses at different levels. The rest (14.3%) had Jersey cows. A higher percentage of smallholder dairy farmers (66.3%) used stall-feeding (cut-and-carry) system than free-range (grazing) system (15.3%) and semi-free range (18.4%). Majority of farmers supplemented their cows with maize bran (68.4%) as compared to dairy mash (31.6%). Natural mating system was more commonly practiced (60%) by dairy farmers in the study area than artificial insemination (40%). In smallholder production, housing and mating systems tend to interact (Chagunda et al. 2002). The majority of farmers that practiced stall-feeding, used artificial insemination (36.7%) compared to those that used natural system of mating (30.6%). More farmers that practiced free range and semi-free range used natural mating system (13.2% and 16.4%, respectively) than artificial insemination (1% and 2%, respectively).

Record keeping is one of the vital components of dairy farming. The majority (64.3%) of the farmers did not keep records. Recording participation was higher for farmers that

**Table 2** Mean number of times (days) of milk rejection at milk bulking group (MBG) in 150 days

FMS	$n$	Mean	SE
Tier 1	29	18a	0.8
Tier 2	39	8b	0.2
Tier 3	30	3c	0.2

Means with different letters within column are significantly different ( $P < 0.05$ )

**Table 3** Economic significance of milk rejection in smallholder dairy farms over either a 150-day or a 1-year period

FMS	$n$	Average milk yield (kg)	REJ	VALUE1 (Malawi Kwacha)	VALUE2 (Malawi Kwacha)
Tier 1	29	5.4	18	6,610	15,863
Tier 2	39	6.4	8	3,482	8,356
Tier 3	30	10.8	3	2,203	5,288

$n$  number of farmers, *FMS* farmer management system, *REJ* mean number of times milk was rejected at MBG, *VALUE1* value (Malawi Kwacha) of milk rejected in 150 days (during study period), *VALUE2* value (Malawi Kwacha) of milk rejected in 1 year (projected annual loss)

used artificial insemination (24.5%) compared to farmers that used natural mating system (11.2%). The results highlight the link between performance recording and mating system.

Smallholder dairy farming just like any small-scale business operation has its challenges. The challenges that farmers faced are presented in Table 1. The results showed that diseases are the major challenge for smallholder dairy production (35.7%). However, the results showed that ranking of challenges among smallholder dairy farmers differed with management practice. Low milk prices and feed scarcity were the major challenges among farmers in tier 1 and tier 2 management categories. Lack of extension services and high feed costs were the most challenging issues for farmers in the tier 3 management system. This highlights the fact that smallholder dairy farmers are not a homogenous group. Rather they are a heterogeneous group with different challenges.

Initial analysis indicated that the frequency of milk rejection at milk bulking group (MBG) from farmers in the different management categories was significantly different ( $P < 0.05$ ). Table 2 shows that milk from farmers in tier 1

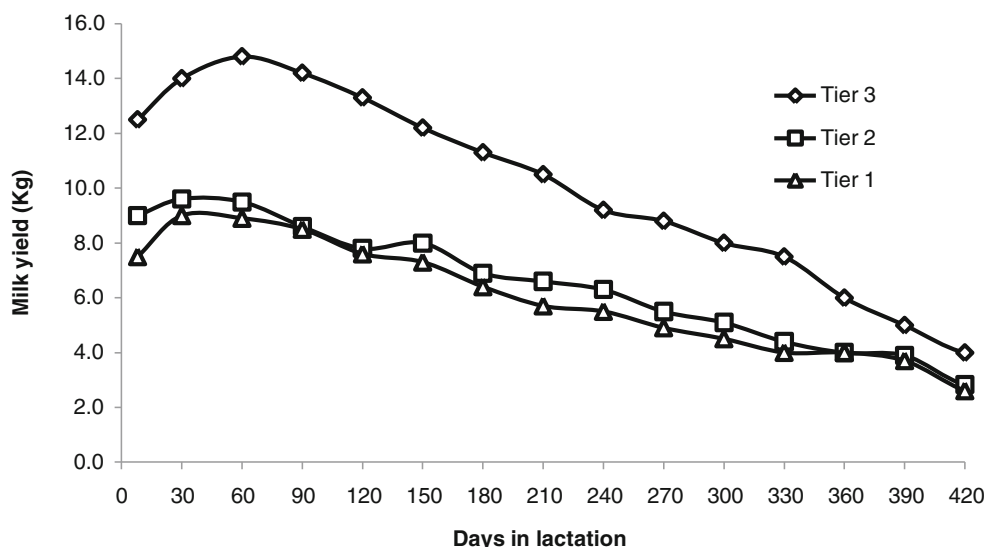
**Table 4** Least square means of body condition scores, milk yield and calving interval of cows under three farm management systems

FMS	$n$	Performance					
		Mean MY	SE	Mean BCS	SE	Mean CI	SE
Tier 1	29	5.4a	0.4	2.1a	0.09	603a	27
Tier 2	39	6.4a	0.3	2.4b	0.07	466b	19
Tier 3	30	10.8b	0.6	2.6c	0.06	404c	17

Means with different letters within column are significantly different ( $P < 0.05$ )

$n$  total number of farmers, *SE* standard error, *FMS* farm management system, *BCS* body condition score, *CI* calving interval (days), *MY* milk yield (kg)

**Fig. 1** Lactation curves of cows from smallholder dairy farms under three farm management systems, tier 1, tier 2 and tier 3



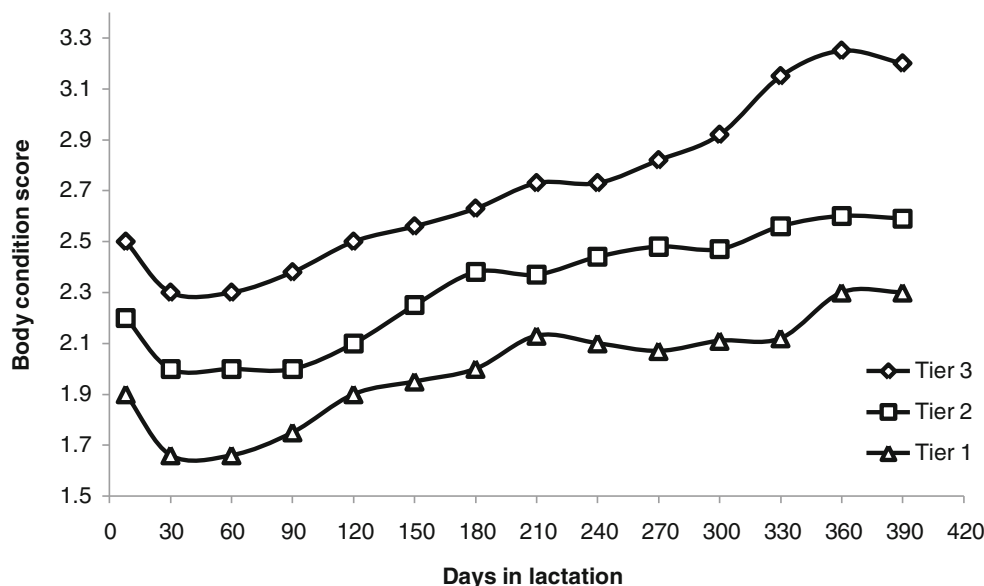
was being rejected a lot more than milk from the other groups (18 times vs. eight times for tier 2 farmers and three times for tier 3 farmers). The number of times milk was rejected at MBG decreased with improvement in farmer management practices.

Economic loss calculated based on milk rejection is presented in Table 3. This was determined based on number of milk rejection, average milk yield and the market price of milk. Farmers in tier 1 management system had the highest loss of 15,863 Malawi Kwacha (MK) per year compared to farmers in tier 2 (MK8, 356) and tier 3 (MK5, 288) management categories. These results suggest that with improvements in management practices in sanitation, milk handling techniques and all the predisposing factors to milk rejection farmers will minimise losses on productivity due to poor milk quality.

Effects of farmer management practices on milk yield, calving interval and body condition score

The least square means of milk yield, body condition score and calving interval are shown in Table 4. Farmer management practices among the three management categories had a significant effect on body condition score, milk yield and calving interval ( $P < 0.05$ ). However, between tier 1 and tier 2 management categories, there was no significant difference in the effect of management practice on milk yield. Cows of farmers in tier 3 management system had the highest mean milk yield, 10.8 (SE=0.6) kg/day while cows of farmers in tier 1 management system had the lowest milk yield, 5.4 (SE=0.4) kg/day. Calving interval of cows ranged from 14 to 20 months. Cows of farmers in tier 1 management system had the longest calving interval (20 months) compared to cows of farmers in

**Fig. 2** Body condition curves of cows from smallholder dairy farms under three farm management systems, tier 1, tier 2 and tier 3



tier 3 management system (14 months). Cows of farmers in tier 3 management system had the largest mean body condition score, 2.6 (SE=0.06) compared to cows of farmers in tier 1 management system, 2.1 (SE=0.09) indicating difference in feeding practices among smallholder dairy farmers.

Over the lactation period, the three farmer management categories showed clear differences between tier 3 and tier 2 and tier 1 management categories but not different between tier 2 and tier 1 management categories (Fig. 1). Lactation curve of cows under tier 1 and tier 2 farmer management categories had flat curves suggesting that milk yield did not increase very much during peak lactation.

Lactation curves for body condition score are presented in Fig. 2. Cows of farmers in tier 1 management system had lowest body condition scores throughout the lactation while cows in tier 3 management system had the highest body condition scores throughout the lactation. Cows from tier 2 had mid-values. In all the three management categories, body condition score for all cows was high at the start of lactation and gradually dropped as the lactation progressed reaching a nadir in the period from day 30 to 60 after calving and picking-off thereafter.

## Discussion

The findings in the current study support the link between farmer management practices (nutrition and welfare) and productivity in smallholder dairy production systems (Olafadehan and Adewumi 2010; Falvey and Chantanthala 1999; Land O'Lakes 2005). The high difference in milk yields among farmer management categories observed in the current study suggests major differences in management practices among smallholder dairy farmers in Malawi. The observed difference in milk yields due to farmer management practices agrees with other findings (Teklerli et al. 2000; Mwale 1999). Land O'Lakes (2005) indicated that yield differences of up to 60% exist among smallholder dairy farmers due to differences in feeding practices. The observation that majority of smallholder dairy farmers do not keep records agrees with other observations in smallholder farming systems. Nicholson et al. (1999) indicated that in most smallholder management systems, no records are kept; the only record that farmers keep is the receipt issued by the milk-collecting centre (MBG) for the supply of milk. The observation that smallholder farmers that use artificial insemination mostly keep records agrees with earlier findings in Malawi (Msiska 2003). It was further observed that feeding and health are the major problems faced by smallholder dairy farmers in Malawi. This agrees with other research done in Malawi (Msiska 2003; Land O'Lakes 2005; Mwale 1999). Low BSC and long calving interval for cows in tier 1 (farms with poor hygiene and poor milk quality) agree with earlier findings that indicate that poor sanitation plays a major

role in predisposing the individual animals to diseases (Falvey and Chantanthala 1999).

Low body condition of cows during lactation, reflect a shortage of nutrients which will have a negative impact on fertility (Wanapat and Chanthakhoun 2011; Washburn et al. 2002; Dunne et al. 1999) and milk yield (Domecq et al. 1997). Farmers in tier 1 management system with cows in low body condition scores during lactation should target improvements in cow feeding to minimising poor cow condition during lactation so that fertility is optimised. The long calving intervals indicate low fertility (Banda et al. 2011) as a result of failure for the cows to have a calf every year.

Milk yield was not significantly different between tier 1 and tier 2 management categories suggesting that the management practices of the two groups are similar. Within the current smallholder dairy management system, there is potential to explore further the inter-relationships that exist between tier 1 and tier 2 management categories. The analyses of farmer management-specific lactation curves, based on milk records, provided the basis for between-farmer management practice comparisons of milk yields. The findings of this study support the link between farmer management practice and milk yield in the dairy cow (Tarawali et al. 2011; Rekik et al. 2002; Teklerli et al. 2000). This analysis demonstrates a link between farmer management practice and milk yield, cow health and fertility, and provides the potential of characterising smallholder dairy production systems using already known parameters at the farm.

## Conclusion

The study highlighted the fact that smallholder farmers are not a homogeneous group and that it is possible to classify smallholder farmers based on management practice in animal welfare and milk quality. Use of such a simple yet novel and robust method could assist in identifying specific problems on the farm and hence help extension workers target appropriate interventions.

**Acknowledgement** This study was conducted as part of the Optimising Smallholder Dairying project portfolio. The financial support from the Scottish Government through the International Development Fund (IDF) is greatly appreciated.

## References

- Anon 1996. Cow nutrition. In, S. Schelling (ed.) *The Comprehensive Reference to the Australian Dairy Industry* (East Hawthorn, Vic., Morescope Publishing and the Australian Dairy Industry Council), 161-90
- Banda, L.J., Kamwanja, L.A., Chagunda, M.G.G., Ashworth, C.J. and Roberts, D.J. 2011. Status of dairy cow management and fertility

- in smallholder farms in Malawi. *Tropical Animal Health and Production*. doi:10.1007/s11250-011-9972-4
- Chagunda, M.G.G., Wollny, C.B.A. and Bruns, E.W. 2002. Potential genetic gain in dairy production of Holstein Friesian cattle applying a selection index. *Tropical Agriculture*, 79, 42–47
- Cook, N.B. 2007. A toolbox for assessing cow, udder, and teat hygiene. Proceedings of the 46th Annual Meetings of the National Mastitis Council, San Antonio, TX (National Mastitis Council, Madison, Wisconsin, USA), 31–43
- Delgado, C., Rosegrant, M. and Meijer S., 2001. The Revolution continues. Annual meetings of the International Agriculture Trade Research Consortium (IATRC), Auckland, New Zealand
- Dunne, L.D., Diskin, M.G., Boland, M.P., O'Farrel K.J. and Sreeman J.M., 1999. The effect of pre- and post-insemination plane of nutrition on embryo survival in beef heifers. *Animal Science*, 69, 411–417
- Falvey L. and Chantanthalaka C, 1999. Smallholder dairying in the Tropics (International Livestock Research Institute, Nairobi, Kenya)
- Gibbons, J.M., Kawonga, B., Gondwe T.N., Chagunda M.G.G. and D. J. Roberts. 2010. Measuring welfare of dairy cattle in Malawi—challenges, constraints and opportunities. The 5th All Africa Conference on Animal Agriculture, Addis Ababa, Ethiopia (All Africa Society of Animal Agriculture)
- Gibbons, J., Lawrence, A.B. and Haskell, M.J. 2009. Responsiveness of dairy cows to human approach and novel objects. *Applied Animal Behaviour Science*, 116, 163–173
- Gipson, T.A and Grossman, M., 1990. Lactation curves in dairy goats: a review. *Small Ruminant Research*, 383–396
- Hanigan, M.D., Rius, A.G., Kolver, E.S and Palliser, C.C., 2007. A redefinition of the representation of mammary cells and enzyme activities in a lactating dairy cow model. *Journal of Dairy Science* 90, 3816–3830
- Ibrahim, N., Abraha, A. and Mulugeta, S., 2011. Assessment of reproductive performances of crossbred dairy cattle (Holstein Friesian × Zebu) in Gondar town. *Global Veterinaria*, 6, 561–566
- Land O'Lakes, 2005. Phase 2 Baseline Survey Report. Lilongwe, Malawi (unpublished report, Land O'Lakes, Lilongwe, Malawi)
- Malawi Government, 1996. Smallholder Dairy Study (unpublished Technical Report, Ministry of Agriculture and Livestock Development, Lilongwe, Malawi)
- Manson, F.J. and Leaver, J.D. 1989. The effect of concentrate: silage ratio and of hoof trimming on lameness in dairy cattle. *Animal Production*, 49, 15–22
- Msiska, A.C.M., 2003. Developing recording systems for smallholder dairy producers in Malawi—a case study of Lilongwe milk shed area (unpublished MSc thesis, Bunda College of Agriculture, University of Malawi)
- Mwale, S.E., 1999. Economic analysis with reference to assumed interactions between genotype and management system in smallholder dairy production in Mzuzu milkshed area—Northern Malawi (unpublished MSc thesis, Bunda College of agriculture, University of Malawi)
- Nicholson, C.F, Thornton, P.K., Mohammed, L., Muinga, R.W., Mwamachi, D.M., Elbasha, E.H., Staal, S.J. and Thorpe, W., 1999. Smallholder dairy technology in coastal Kenya: an adoption and impact study (unpublished report International livestock Research Institute (ILRI), Nairobi, Kenya)
- Olafadehan, O.A. and Adewumi, M.K., 2010. Livestock management and production system of agropastoralists in the derived savanna of South-west Nigeria. *Tropical and Subtropical Agroecosystems*, 12, 685–691
- Rekik, B., Gara, A.B., Hamouda, M.B., and Hammami, H., 2002. Fitting lactation curves of dairy cattle in different types of herds in Tunisia. *Journal of Animal Science*, 20, 63–69
- Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford, K.J and Berry, D.P., 2009. Body condition score and its association with dairy cow productivity, health and welfare: a review. *Journal of Dairy Science* 92, 5769–5801
- Rutherford, K.M.D., Langford, F.M., Jack, M.C., Sherwood, L., Lawrence, A.B. and Haskell, M.J. 2008. Hock injury prevalence and associated risk factors on organic and non-organic dairy farms in the United Kingdom. *Journal of Dairy Science*, 91, 2265–2274
- SAS System for Windows version 8, 1999. SAS Institute Inc. Cary, NC, USA
- Sørensen, J.T., Sandøe, P. and Halberg, N., 2001. Animal welfare as one among several values to be considered at farm level: the idea of an ethical account for livestock farming. *Acta Agriculturae Scandinavica, Section A—Animal Science Supplement*, 30, 11–16
- Stockdale, C.R. 2001. Body condition at calving and the performance of dairy cows in early lactation under Australian conditions: a review. *Australian Journal of Experimental Agriculture*, 41, 823–839
- 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
- Tekerli, M., Akinci, Z., Dogan, I. and Ackan, A., 2000. Factors affecting the shape of lactation curves of Holstein cows from the Balikesir province of Turkey. *Journal of Dairy Science*, 83, 1381–1386
- Waltner, S.S., McNamara, J.P. and Hillers, J. K., 1993. Relationships of body condition score to production variables in high producing Holstein dairy cows. *Journal of Dairy Science*, 76, 3410–3419
- Wanapat, M. and Chanthakhoun, V., 2011. Food-feed-systems for smallholder livestock farmers. *FAO Animal Production and Health Proceedings*, 11, 69–74
- Washburn S.P., Silvia W.J., Brown C.H., McDaniel B.T. and McAlister A.J., 2002. Trends in reproductive performance in south-eastern Holstein and Jersey DHI herds. *Journal of Dairy Science*, 85, 244–251
- Wildman, E. E., Jones, G. M., Wagner, R.L., Boman, H.F., Troutt, Jr and Lesch, T.N., 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. *Journal of Dairy Science*, 65, 495–501