Breeding programs for smallholder farming systems: 2. Optimization of a cooperative village breeding scheme for Menz sheep

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Abstract

A simulation study was conducted to optimize a cooperative village-based sheep breeding scheme for Menz sheep of Ethiopia. Genetic gains and profits were estimated under 9 levels of farmers' participation and 3 scenarios of controlled breeding achieved in the breeding program, as well as under 3 cooperative flock sizes, ewe-to-ram mating ratios and durations of ram use for breeding. Under fully controlled breeding, i.e. when there is no gene flow between participating (P) and non-participating (NP) flocks, profits ranged from Birr 36.9 at 90% of participation to Birr 21.3 at 10% of participation. When there was gene flow from the NP to P flocks, profits declined from Birr 28.6 to Birr -3.7 as participation declined from 90% to 10%. Under the two-way gene flow model (i.e. when P and NP flocks are herded mixed in communal grazing areas), NP flocks benefited from the genetic gain achieved in the P flocks, but the benefits declined sharply when participation declined beyond 60%. Our results indicate that a cooperative breeding group can be established with as low as 600 breeding ewes mated at a ratio of 45 ewes to one ram, and the rams being used for breeding for a period of two years. This study showed that farmer cooperation is crucial to effect genetic improvement under smallholder low-input sheep farming systems.

Key words: Designing breeding program; smallholder system; cooperative breeding; farmer participation; sheep.

1. Introduction

Despite the large numbers and importance of small ruminants in developing countries, information on sustainable genetic improvement programs under smallholder production circumstances is scarce, especially for the adapted indigenous breeds (Kosgey et al., 2006). Within-breed genetic improvement of small ruminants under smallholder systems is limited by both technical and infrastructural constraints (Kosgey et al., 2007). The major technical limitations are small flock sizes, lack of pedigree and performance records, multiple and diverse breeding goals, poor infrastructure and institutional arrangements, including inadequate farmers' organizations at the village level to effectively participate in breeding schemes (Osinowo and Abubakar, 1988) as well as the difficulties of achieving controlled mating under communal grazing to maximize the use of selected sires. To overcome these challenges, village-based breeding schemes that suit the low-input, smallholder farming systems have been suggested and designed (Ahuye et al., 2005; Kahi et al., 2005; Wurzinger et al., 2008; Gizaw et al., 2009; Mueller, 2010; Haile et al., 2011; Mirkena et al., 2012).

A cooperative village sheep breeding scheme that suits the smallholder sheep farming system in Menz region of Ethiopia has been designed for Menz sheep improvement (Gizaw et al., 2009). The scheme involves cooperation among farmers in a village, where they select breeding rams from across the whole flocks in the village taken as one big breeding flock and the selected rams are used communally. However, the effectiveness of such a design is affected by lack of participation by some of the villagers in the cooperative village breeding group which could in turn affect the level of controlled breeding and genetic gain achieved. Furthermore, effectiveness of cooperative village breeding groups in terms of genetic progress achieved and rate of inbreeding is determined by the village size which varies across the Menz sheep breeding tract. It has also been observed that some of the Menz farmers' traditional breeding practices such prolonged use of selected rams could increase the generation interval and thus the genetic progress achieved.

The overall objective of the current simulation study was therefore to optimize genetic gains and annual returns from the Menz sheep cooperative village breeding program. Specifically, the study aims to estimate genetic gains/profits at different levels of participation of farmers in a village, under different levels of controlled breeding achieved and with different cooperative village sizes and farmers' ram use practices.

2. Materials and Methods

2.1. Basic design of the breeding scheme

Description of Menz sheep production system, farmers' breeding goal and selection criteria are given in Part 1 of this paper. A cooperative village breeding scheme was designed for selective breeding of Menz sheep (Gizaw *et al.,* 2009). A village is defined here as a group of contiguous communities sharing communal grazing areas with little or no interference from other village flocks and which have about 1200-1500 breeding ewes. The scheme was designed to benefit from the existing sheep production practices, while ensuring that the existing bottlenecks such small household flock sizes and uncontrolled mating were taking into account and overcome. The key elements of the design were defining the organization of the breeding program, recording scheme and selection and mating plans.

Farmers in a village were organized as a cooperative breeding group. The breeding group was formed by villagers whose flocks share common grazing fields and are watered together, hence can be considered as one big interbreeding population, separate from other villages. For the current simulation study a cooperative village with a total breeding flock of 1500 ewes was modeled. All animals in the village were uniquely identified using ear tags and pedigree and performance data including date of birth, birth weight, three and six month weights of lambs were to be collected by one of the farmers trained as coordinator of the breeding activities and enumerator.

A one-tier breeding structure was adopted, i.e. selection was implemented in the whole village sheep population. Selection was implemented across flocks in the village. All six month old ram lambs from all flocks in the village were evaluated together as cohorts. The best young rams were to be selected by a committee of farmers based on their six-month weight. This criterion was further subjected to farmers' selection criteria which have been defined earlier (Getachew, 2008; Gizaw *et al.*, 2010; Duguma et al., 2011). The selected rams are assigned to ram groups which are organized in such a way that the rams would be used and managed communally. All unselected ram lambs and old breeding rams were culled at each round of selection, castrated, fattened and sold to establish a revolving fund which was then used to compensate or pay for the selected rams.

2.2 Alternative scenarios of the breeding scheme

Different scenarios of farmer participation in the cooperative breeding program, controlled breeding, cooperative group size and ram use practices described below were modeled using the method developed for this purpose and incorporated in the computer program ZPLAN (Willam, et al., 2008). ZPLAN is based on the gene flow method (Hill 1974; McClintock & Cunningham 1974) and selection index procedure. The program calculates a number of outcomes such as annual monetary genetic gain for the aggregate genotype, annual genetic gain for single traits, discounted return and discounted profit for a given investment period.

Levels of farmer participation and controlled breeding

According to the basic design of the scheme, all the villagers/flocks sharing communal grazing need to participate in the cooperative group breeding to achieve controlled mating. However, all the farmers may not participate. Thus 9 levels ranging from 90% (Level 1) to 10% (Level 9) of the villagers participating in the cooperative group were modeled. Further, it is expected that unselected/unimproved rams from non-participating farmers may dilute the selection effort of the cooperative group. Accordingly three scenarios of controlled breeding were modeled. Each scenario of controlled mating was evaluated under the 9 levels of participation. The first scenario (No gene flow) assumes that both participating (P) and non-participating (NP) groups herd their flock separately and thus there is no gene flow between P and NP flocks. In the second scenario (One-way gene flow) there is a one-way gene flow, i.e. the P group may herd their flocks separately but still rams from the NP flocks may intrude and mate with P ewes. Scenario 3 assumes a complete mix of the P and NP flocks and a two-way gene flow.

Optimization of cooperative group size and ram use practices

The village sizes, quantified in terms of total number of breeding ewes in a cooperative village, in Menz region varies from village to village. Thus smaller villages may need to organize together to achieve acceptable effective ewe population size to sustain genetic improvement. To this end, three levels of cooperative village sizes of 600, 1500 and 3000 breeding ewes were modeled to find the most optimal cooperative group size. Duration of ram use for breeding of 1, 2 and 3 years, and ewe to ram mating ratio of 15 (villagers traditional practice), 30 and 45 (research center practice) ewes to one ram were evaluated. Optimization of cooperative group size and ram use practices were evaluated at the basic level of the breeding scheme, i.e. 100% participation of villagers.

2.3 Input parameters for modeling schemes

The inputs for the biological, technical and economic parameters used to model the breeding scheme using ZPLAN are shown in Table 1. The input levels presented in the table are for the basic scheme (see Section 2.1). The levels for number of breedable ewes, lifetime use of rams, and mating ratio vary for the alternative breeding schemes as described above in Section 2.2. The fixed costs include salaries for village coordinators, and costs of supplies and communications. Costs for animal identification and recording traits are included as variable costs. The breeding program was planned for 10 years. The phenotypic and genetic parameters and economic values used to design the breeding schemes are presented in Table 2 in Part 1 of this paper.

Table 1. Biological, technical and economic parameters for the basic scheme

Input parameters	
Number of breedable ewes	1500
Lifetime use of rams (years)	3.0
Lifetime use of ewes (years)	7.0
Number of lambings per year	1.37
Mating ration (Number of females per ram)	15
Lambing interval (years)	0.73
Conception rate	0.90
Age at first lambing (years)	1.5
Litter size	1.02
Survival rate of rams	0.85
Survival rate of ewes	0.85
Lamb weaning rate	0.85
Proportion of rams suitability for breeding	0.90
Fixed costs per ewe (Birr)	4.80
Variable costs per ewe (Birr)	5.29

3 Results

3.1 Effect of level of participation and controlled breeding

The monetary genetic gains per year in the breeding objective under varying levels of farmers' participation and under different scenarios of controlled breeding in the cooperative village breeding program are summarized in Figure 1. The genetic gains in the breeding objective were calculated as the sum of the products of the genetic gains in the component traits (SWT, MWT, PWS and LTS) and their corresponding economic values. Under fully controlled breeding, i.e. when there is no gene flow between participating (P) and non-participating (NP) flocks, genetic gains ranged from Birr 5.7 (90% participation) to Birr 5.5 (10% participation); the corresponding profits from investment in the breeding program ranged from

Birr 36.9 to 21.3 per year (Figure 2). When there was gene flow from the NP to P flocks, genetic gains and profits declined from Birr 4.6 and 28.6 to Birr 0.1 and -3.7 as participation declined from 90 to 10%. The genetic gains and profits to the whole village population including the P and NP villagers were higher under the two-way gene flow model (i.e. when flocks of P and NP were completely mixed) than the one-way gene flow from NP to P flocks (Figures 1 and 2).

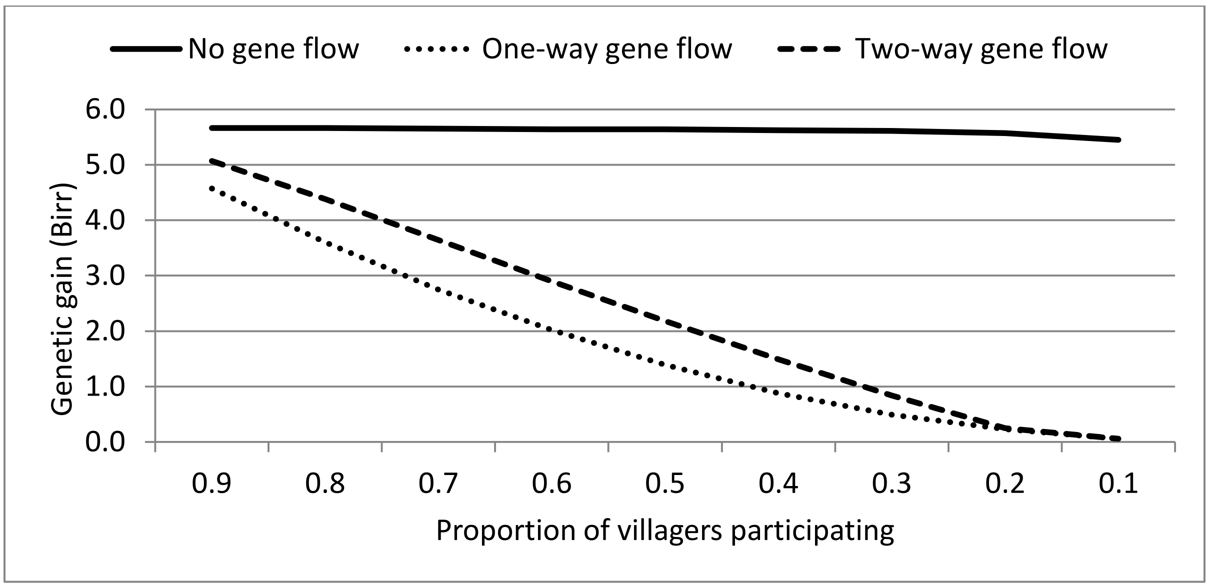

Figure 1. Monetary genetic gain per year under varying levels of participation of villagers and different scenarios of controlled breeding (gene flow between participating and non-participating flocks) in Menz sheep cooperative village breeding program. (The genetic gains in the breeding objective were calculated as the sum of the products of the genetic gains in the component traits (SWT, MWT, PWS and LTS) and their corresponding economic values).

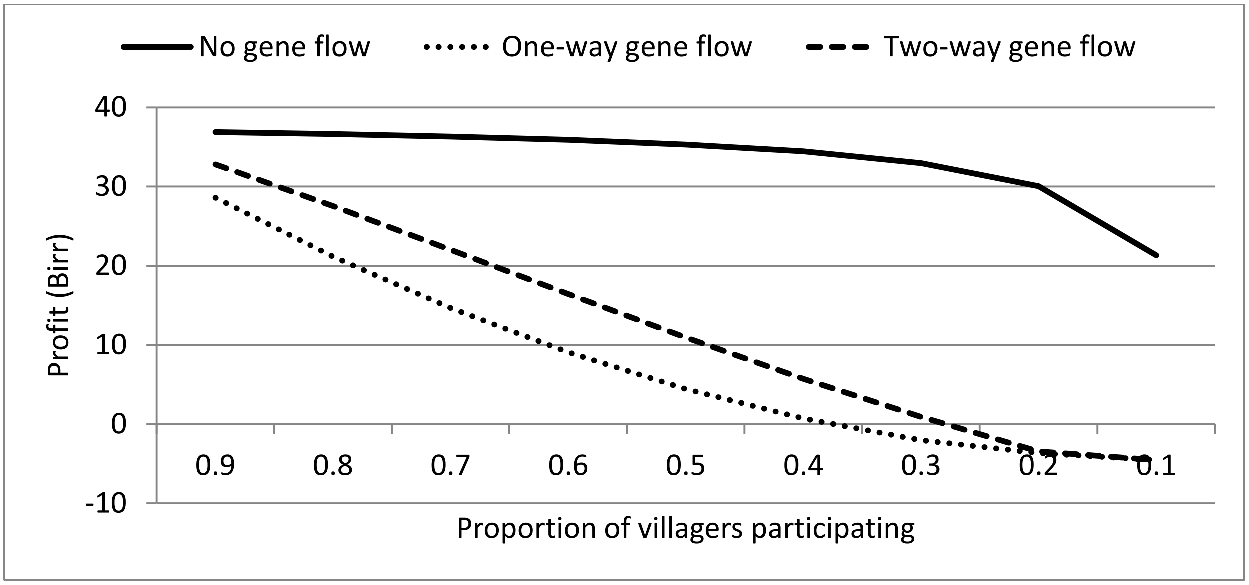

Figure 2. Profits per ewe per year under varying levels of participation of villagers and different scenarios of controlled breeding (gene flow between participating and non-participating flocks) in Menz sheep cooperative village breeding program

Disaggregating the genetic gains and profits between the P and NP villagers/flocks showed that under the no gene flow and one-way gene flow scenarios, there was no genetic gain in the NP flocks and thus there were no costs, returns and profits for the NP villagers. However, under the two-way gene flow model (Figure 3 and 4) NP flocks benefited from the genetic gain achieved in the P flocks. The monetary genetic gain in the NP flock ranged from 100% to 0.0% of the gain achieved in the P flocks (Figure 3). The NP villagers' profits, which is rather their 'return' as they incurred no cost of selection, leveled around Birr 7 per ewe per year until the participation of villagers in the breeding program fall below 60%. A decline beyond 60% of villagers' participation resulted in sharp decline in profits for both NP and P villagers (Figure 4).

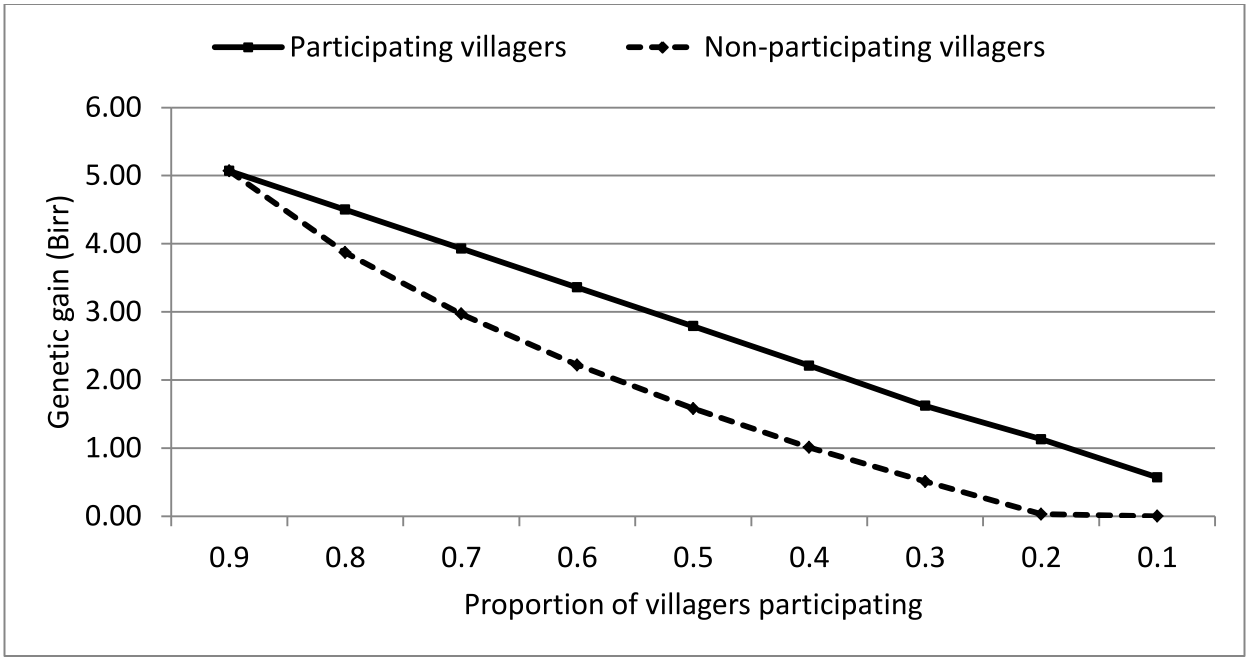

Figure 3. Monetary genetic gain per year in village sheep flocks participating and not participating in a cooperative village breeding program under two-way gene flow model (i.e. rams of each flock mating with ewes of either flock)

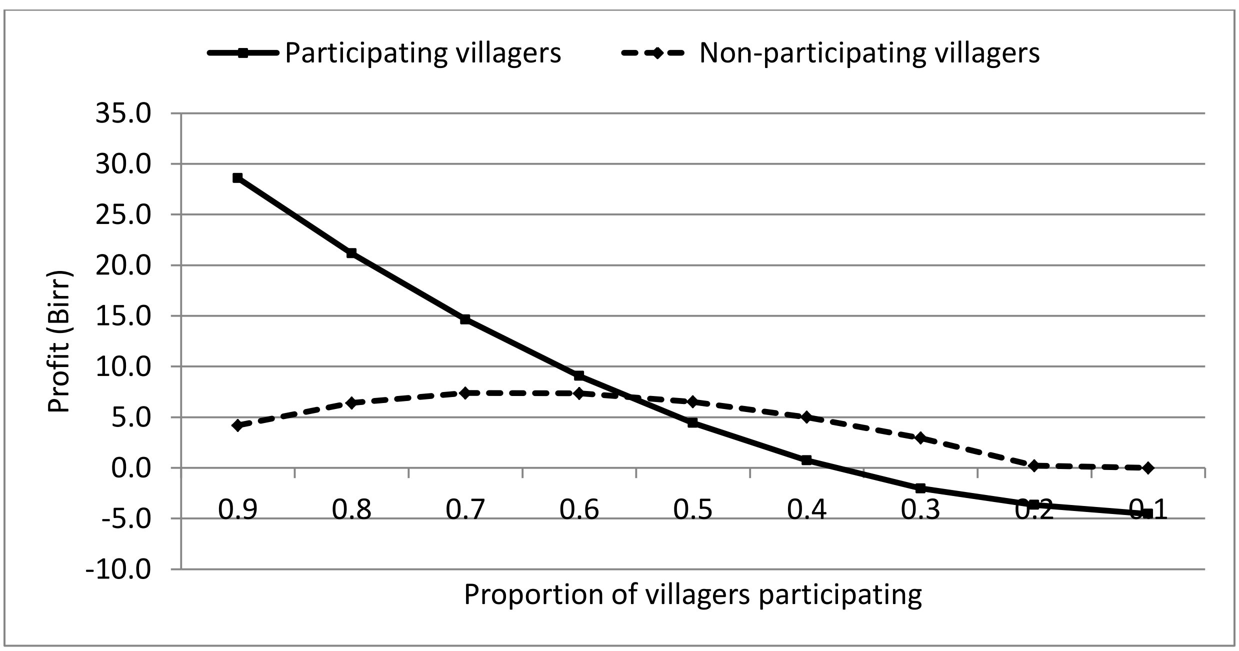

Figure 4. Profit per ewe per year in village sheep flocks participating and not participating in a cooperative village breeding program under two-way gene flow model (i.e. rams of each flock mating with ewes of either flocks)

3.2 Effects of village size and ram use practices

Genetic gains in the breeding objective and profits from investment in the Menz sheep village breeding program simulated in this study under varying levels of village size, ewe to ram mating ratio and duration of ram use for breeding are presented in Table 2. Genetic gains in the breeding objective increased on the average by 0.56% and 0.18% as the size of the cooperating villages (i.e. number of breeding ewes) increased from 600 to 1500 ewes and from 1500 to 3000 ewes, respectively. The corresponding increases in profits were 0.75% and 0.16% as the size of the cooperating villages increased from 600 to 1500 ewes and from 1500 to 3000 ewes, respectively. Genetic gains and profits increased by 12.95% and 16.59% respectively when number of ewes mated to a ram increased from 15 to 30, and by 6.55% and 8.17% when number of ewes mated increased from 30 to 45. When use of rams for breeding increased from one to two years, average genetic gain increased by 5.56%, but profit declined by 0.85%. Both genetic gains and profits declined by 1.27% and 9.34% as ram use increased from two to three years.

Table 2. Monetary genetic gain and profits in a cooperative Menz sheep village breeding program under varying cooperating village size, ewe to ram mating ratios and duration of ram use for breeding

Village size (No of ewes)	Mating ratio	Ram use (years)	Genetic gain (Birr) [†]	Profit (Birr)
600	15	1	4.52	31.16
600	15	2	4.97	32.41
600	15	3	4.98	30.09
600	30	1	5.39	38.98
600	30	2	5.66	38.31
600	30	3	5.57	34.82
600	45	1	5.84	43.09
600	45	2	6.03	41.39
600	45	3	5.89	37.35

1500	15	1	4.53	31.25
1500	15	2	4.98	32.56
1500	15	3	5.01	30.28
1500	30	1	5.41	39.15
1500	30	2	5.69	38.58
1500	30	3	5.62	35.17
1500	45	1	5.87	43.34
1500	45	2	6.07	41.79
1500	45	3	5.95	37.83
3000	15	1	4.54	31.29
3000	15	2	4.99	32.61
3000	15	3	5.01	30.34
3000	30	1	5.41	39.21
3000	30	2	5.7	38.68
3000	30	3	5.63	35.28
3000	45	1	5.88	43.42
3000	45	2	6.09	41.92
3000	45	3	5.97	38

[†]The genetic gains in the breeding objective were calculated as the sum of the products of the genetic gains in the component traits (SWT, MWT, PWS and LTS) and their corresponding economic values.

Discussion

It has been reiterated that village-based cooperative breeding organizations are an alternative approach for achieving genetic and husbandry improvements as well as sustainable institutional development in smallholder livestock farming systems (Solkner et al., 1998; Ahuya et al., 2005; Kahi et al., 2005). Yet, observations in a pilot Menz sheep cooperative village breeding program and elsewhere (Osinowo and Abubakar, 1988; Wurzinger et al., 2008) revealed that getting farmers actively involved in cooperative breeding has been a challenge and is thus an important issue to be considered when organizing farmers' breeding groups.

The current simulation study clearly showed that the level of participation of villagers in a cooperative village breeding program is a critical factor for its effectiveness as genetic progress declines with declining participation of villagers. Our results also indicate (Figure 4) that non-participation in a cooperative breeding could be tempting to villagers as non-participants could as well achieve genetic progress in their flocks without incurring selection costs. However, both participating and non-participating villagers would lose in the end as the proportion of non-participating villagers rises beyond 60%. Thus facilitating the conditions for maximum participation of villagers in designing and implementing a cooperative village breeding program is essential. Wurzinger et al. (2008) and Kosgey et al. (2007) suggested that an approach for farmers to actively participate and invest more time and money in a breeding program would be that the breeding program needs to be embedded in an integrated approach where other aspects of animal production like animal health and marketing of products are covered. Access to, and provision of loans, also allows farmers to participate in breeding programs (FAO, 1988; Kosgey, 2004).

Matings within smallholder flocks are largely uncontrolled and organized mating would naturally demand more labor, which is a serious problem at the time of land preparation for sowing or harvesting of crops (Gatenby, 1986). The consequence of lack of participation by some members of a village in the village's cooperative breeding group is the dilution of the genetic improvement effort of participating villagers by non-participating flocks due to uncontrolled breeding practices (i.e. mating of ewes of participating flocks by unselected rams from non-participating flocks). The current results also showed that the effectiveness of a cooperative breeding group is not considerably affected by a declining membership per se, but by the level of controlled breeding achieved by the villagers participating in the cooperative breeding. That is, if the cooperative group managed to avoid gene flow from the non-participating flocks, the genetic progress in their flocks is not affected significantly. However, herding flocks separately to avoid gene flow among village flocks is seldom practical under communal herding practiced in most smallholder farming systems.

Although low level of participation and hence smaller cooperative group size (i.e. number of breeding ewes) per se does not have a significant effect on the genetic progress achieved in the short-term, smaller cooperating flocks would in the long run have higher rate of inbreeding, lower within-population genetic diversity and hence reduced genetic response to selection. A study on the optimal size for a cooperative Menz sheep breeding group (Gizaw et al., 2009) recommended that an ewe flock of at least 600 joined to 15 rams each generation need to be organized to maintain an acceptable rate of inbreeding of 0.01 (van Arendonk and Bijma, 2003). The rate of inbreeding was not calculated in the current simulation, but the cooperative breeding flock simulated (1500 breeding ewes) is much larger than the recommended (Gizaw et al., 2009) minimum size to maintain genetic diversity and assure long-term genetic progress.

Besides to the level of villagers' participation in a cooperative breeding group, cooperative group sizes are also determined by the settlement pattern of communities sharing communal grazing areas. Thus some villages could be too small and may have to cooperate with contiguous villages to establish breeding populations with acceptable effective population size to maintain genetic diversity and long-term genetic responses. However, increasing the cooperative group size beyond 1500 ewes yields only marginal returns to investment as shown in the current study. The current and previous results (Kosgey, 2004; Mirkena et al., 2012) indicate that more important parameters that affect the rate of inbreeding, genetic progresses and returns to investment are the ewe to ram mating ratio and duration of ram use for breeding. Farmers in Menz region traditionally keep a number of rams and for a longer duration for breeding than recommended here and in a previous study ((Mirkena et al., 2013). However, when designing breeding programs with the recommended levels of the above parameters, farmers' sheep production objectives need to be considered. For instance, sheep production and marketing objective of farmers in Menz region of Ethiopia is to keep large number of yearling males for breeding and as a source of capital to be sold as the need for cash arises and to keep some of the rams for a period of about 2.3 years and finish them for festival markets (Gizaw et al., 2011).

4 Conclusion

Farmer cooperation is crucial to implement effective genetic improvement under low-input smallholder sheep farming systems. This is because village resources (herding areas, grazing areas, watering resources, and breeding rams) which are required to implement effective genetic improvement programs are owned and/or used communally. To ensure high and active farmer participation, farmers need to be involved during the design and implementation of the program, and the program needs to be integrated with feeding, health, marketing and input supply components.

The highest genetic gains in the breeding objective as defined in this study could be obtained from establishing a cooperative village breeding group consisting as low as 600 ewes mated at a ratio of 45 ewes to one ram which can be used for breeding for a period of two years; but the highest profit is obtained from using rams for one year, other conditions remaining the same. However, breeding programs need to be designed in consultation with the target producers.

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