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Title: Genetic progress and economic benefit of sheep community-based breeding programmes out- and up-scaling options in Ethiopia

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Abstract: The expected genetic progress and economic benefit from implementing three sheep Community Based Breeding Programme (CBBP) out- and up-scaling strategies were investigated. Strategy 1 is to replicate average existing CBBPs, Strategy 2 is to increase the number of breeding males produced by average CBBPs and Strategy 3 is to intensify the use of breeding males with artificial insemination (AI). The strategies were modelled using Ethiopian Menz sheep field and market data and genetic progress and economic benefit were calculated using gene flow techniques. Different breeding program durations (T), planning horizons (H) and discount rates (r) were tested when breeding objective and selection criterion is six-month weight. Genetic progress expected in average existing CBBPs is 0.11 kg/year in the Nucleus and accumulated discounted economic benefit is 54560 $ with a return to investment of 5.2 when T = H = 20 years and r = 0.07. Thus, Strategy 1, replicating ongoing CBBPs, is highly beneficial. Strategy 2 was tested assuming 200, instead of 32, rams distributed to Base herds from the Nucleus and an additional cost of these rams of 10% their present market value, both assumptions considered realistic situations. Return to investment with this strategy results in 24.7 $ per $ invested. Additional cost of improved rams would need to be 2.5 times higher of current market value to make this strategy unprofitable. Strategy 3, taking advantage of AI, was tested in two ways, using fewer males to increase selection differential in nucleus (Case A) and increasing the number of females served with improved males in general flocks (Case B). Operational feasible AI programmes were modelled for both cases. Genetic progress of six-month weight in the Nucleus of a CBBP increase to 0.14 kg/year and return to investment results in 2.4 for Case A and 1.6 for Case B. Thus, Strategy 3 increases genetic progress by almost 30% of the expected genetic progress in average current CBBPs but return to investment is lower than in strategies without AI, this is due to substantial additional costs of AI programmes.

- Out- and up-scaling sheep Community Based Breeding Programmes (CBBPs) in Ethiopia are warranted with high returns to the necessary investments.
- Genetic progress in six-month live weight in such systems is expected to be 0.11 kg/year.
- Replicating already operating CBBPs and increasing the number of breeding males supplied to general herds return more than 5 $ per 1 $ invested in long term breeding programmes.
- Using artificial insemination as an out-scaling strategy would further increase genetic progress and dissemination but would require consideration of substantial additional costs.

Genetic progress and economic benefit of sheep community-based breeding programmes out- and up-scaling options in Ethiopia

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Abstract

The expected genetic progress and economic benefit from implementing three sheep Community Based Breeding Programme (CBBP) out- and up-scaling strategies were investigated. Strategy 1 is to replicate average existing CBBPs, Strategy 2 is to increase the number of breeding males produced by average CBBPs and Strategy 3 is to intensify the use of breeding males with artificial insemination (AI). The strategies were modelled using Ethiopian Menz sheep field and market data and genetic progress and economic benefit were calculated using gene flow techniques. Different breeding program durations (T), planning horizons (H) and discount rates (r) were tested when breeding objective and selection criterion is six-month weight. Genetic progress expected in average existing CBBPs is 0.11 kg/year in the Nucleus and accumulated discounted economic benefit is 54560 $ with a return to investment of 5.2 when T = H = 20 years and r = 0.07. Thus, Strategy 1, replicating ongoing CBBPs, is highly beneficial. Strategy 2 was tested assuming 200, instead of 32, rams distributed to Base herds from the Nucleus and an additional cost of these rams of 10% their present market value, both assumptions considered realistic situations. Return to investment with this strategy results in 24.7 $ per $ invested. Additional cost of improved rams would need to be 2.5 times higher of current market value to make this strategy unprofitable. Strategy 3, taking advantage of AI, was tested in two ways, using fewer males to increase selection differential in nucleus (*Case A*) and increasing the number of females served with improved males in general flocks (*Case B*). Operational feasible AI programmes were modelled for both cases. Genetic progress of six-month weight in the Nucleus of a CBBP increase to 0.14 kg/year and return to investment results in 2.4 for *Case A* and 1.6 for *Case B*. Thus, Strategy 3 increases genetic progress by almost 30% of the expected genetic progress in average current CBBPs but return to investment is lower than in strategies without AI, this is due to substantial additional costs of AI programmes.

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1. Introduction

In Ethiopia several Community Based Breeding Programmes (CBBPs) for sheep and goats are operating for some time and genetic progress in growth traits and reproduction has been observed together with other socio-economic benefits (Mueller et al., 2015). This has led to proposals of out- and up-scaling such programs. The following three strategies were proposed (Mueller et al., 2017):

Strategy 1: Out-scaling with more CBBPs considering current production situation

Strategy 2: Up-scaling with more males produced per CBBP

Strategy 3: Up-scaling with more intense use of males

In any case, additional investments will be needed. Policy-makers, donors and investors need a-priori or a-posteriori evaluations of breeding programmes to make objective decisions regarding opportunities to start investing or continue investing in such programmes. Socio-economical evaluation criteria and indicators were summarized by FAO (2010) and those specifically relevant for CBBPs were given by Lamuno et al. (2018). Evaluations in terms of monetary incomes and costs are often a decisive component of socio-economic evaluations. In animal breeding programmes, evaluations need to take account of the genetic progress in relevant traits and the dissemination of improved genes in overlapping generations across the target population (Weller, 1994). The key to do this is to consider the flow of improved genes in the population over time (Hill, 1974).

In this study we attempt to evaluate the expected benefit from implementing the proposed three CBBP out- and up-scaling strategies using gene flow techniques and field data. Sensitivity to parameter assumptions will also be tested.

2. Methods

2.1. Reference CBBP

Current CBBPs in Ethiopia include several local goat and sheep breeds in a variety of environments and production systems. To study genetic progress and economic benefit of out- and up-scaling strategies, a reference CBBP was used. In this exercise an average Menz sheep CBBP is taken as reference. Menz sheep CBBPs are the first ones implemented in the country and their characteristics are well documented. Menz is located in the Ethiopian highlands at about 280 km north-east of Addis Ababa, with an altitude range of 2,700 to 3,300 m.a.s.l. The Menz area is considered as the epicenter of distribution of the Menz breed. The Menz breed is one of the few coarse woolly fat-tailed sheep types, adapted to the high altitude precipitous terrain with scarcity of feed and where production of crop is limited due to extreme low temperature and drought, in the cool highlands. This is a hardy small breed, which controls the level of internal parasite infection and is productive under low input production circumstances of the degraded ecosystems (Getachew et al., 2010).

Average figures from five Menz sheep CBBPs (Molale 1, Mehal-meda 1, Mehal-meda Tsehay-Sina, Molale-Kasele and Dargegn) are used to describe a typical CBBP. Average number of breeding ewes, rams, reproduction rates, survival rates and selection procedures are taken from a previous report (Mueller et al., 2017) adjusted and complemented with additional field and market information. We express incomes and costs of the breeding program in US Dollars.

2.2. Breeding objective and selection criterion

The breeding objective for the reference CBBP needs to be defined. In general, communities expect from a breeding program the continuous birth of animals with improved levels in the traits of interest. Usually such traits are of economic, biological or social importance. Suppose H is the breeding objective function with target traits weighed by their importance and suppose selection criterion is I, where I is an index of traits weighted in such a way that the correlation between H and I is maximized. Usually the importance given to the different objective traits relates to its economic value. Recently it has been shown in Ethiopian Menz sheep areas that there is a fair congruence between farmers' preferences for traits and economic values of traits, both in terms of the rankings of traits and their relative weights (Gizaw et al., 2018).

The breeding objective and selection criterion (measurements, scores, etc.) may or may not be the same. Traits may be expressed at different ages (fleece weights) and may be expressed directly (slaughter weight) or maternally (litter size). The basic benefit calculation models would not change with different breeding objectives but of course the scale of the benefit would depend on traits in H and I. For simplicity, the present exercise assumes breeding objective and selection criterion to be the same (H = I). Slaughter weight (SWT) adjusted to 6 months of age is taken as the breeding objective and selection criterion, as this is in fact a major target trait in all current CBBPs. Strictly, sheep at not necessarily slaughtered at that age, rather it is when farmers make selection decisions. We mimic farmers experience and use 6 months weight as selection trait.

2.3. Tested out- and up-scaling strategies

The reference CBBP is used to model and test the three strategies proposed by Mueller et al. (2017). Table 1 summarizes the main features of the models used.

2.4. Modelling the impact of additional CBBPs (Strategy 1)

The first strategy to reach a greater target population with genetic improvement is to increase the number of CBBPs. To calculate the benefit of an additional CBBP, a model (Model 1) is developed in an Excel spreadsheet following the example of an investment evaluation for a simplified sheep Nucleus system which provides males to a Base population presented by FAO (2010, page 118). In terms of the genetic structure, CBBPs are dispersed open Nucleus systems. Superior females are identified as Nucleus dams producing sires for the whole community herd. Since any female progeny can qualify as a Nucleus dam, the Nucleus is “open” to genes from the whole herd. Strictly, the whole community herd is a closed Nucleus itself producing sires for own use and surplus sires for non-CBBP members (here called Base population). Thus, genetic progress will be calculated in Nucleus and Base population and economic evaluation will include discounted economic benefit (income-cost) as the sum of benefits in Nucleus and Base. In this first out-scaling strategy we model and analyse the benefit arising from one CBBP with average characteristics and parameters of those CBBPs currently in place. In a previous report (Mueller et al., 2017) core target populations were defined for each sheep breed and the number of CBBPs necessary to reach these core target populations was estimated. If it is of interest to calculate the benefit of a program targeting the whole core population of a breed, then the resulting benefit of one average CBBP would need to be multiplied by the number of new CBBPs necessary. The model evaluates a breeding program starting with a Nucleus herd in which parents have been selected for the first time so that the average genetic selection differential is reflected in their progeny born in year 0. Average genetic selection differential is calculated as i x SD x h^2 above initial trait level. Here i is the average standardized selection differential (based on proportion of replacement males and females selected from a normal distribution), SD the standard deviation of the trait and h^2 its heritability. First lambing of improved animals will be at 2 years of age and breeding value of new progeny will then add the same genetic selection differential to the new trait level. This new trait level will remain the same throughout the life of the progeny batch. Since the trait considered is slaughter weight (slaughter being sometime before 1 year of age) first income from improved animals in the Nucleus is set to year 1 after mating of parents.

The breeding program will have costs. The costs to consider are those additional to the regular herd running costs. Such additional costs may be incurred at implementation stage or during operation. Implementation costs are those incurred at the start of a CBBP program (year = 0). For example: collection yard construction (estimated 400 $), scale (20 $), training (200 $), ear tags for founder flock (1000 x 0.29 $ = 290 $) and ear tag applicator (40 $). Operational costs are those incurred annually (year 0 to T). For example: ear tags for lambs (1000 x 1.22 x 0.29 $ = 354 $) and wages of enumerator plus supervision (555 $). The additional cost of improved young rams paid by Base farmers is an additional income for Nucleus farmers, thus the value of such a young ram selected for breeding does not change the Nucleus + Base figures but allocates correctly the cost and income from the transaction. All costs and incomes from year = 1 onwards are discounted to values of year = 0 using a discount rate which is independent of inflation (supposing inflation rates of costs and incomes are similar) but depends on the investment perspective. Projects of strategic national interest consider low discount rates whereas projects of private business interests usually consider high discount rates. Amer et al. (2007) analysed Great Britain's national sheep breeding program with discount rates between 2 and 10%. Here we use as a reference discount rate 7%.

The reference input parameters used to run Model 1 are in Table 2, together with its justification or source.

2.5. Modelling the impact of more males produced by an ongoing CBBP (Strategy 2)

The second avenue to reach a larger population with improved males is to increase the number of males produced by present CBBPs in order to have more surplus males to be sold to Base population farmers. It was calculated that about seven times more males could be produced in average Menz CBBPs than is presently the case (282 instead of 40, see Table 4 in Mueller et al., 2017). Of course there must be a demand for CBBP males from Base farmers and a disposition to pay at least for the extra costs involved to motivate CBBP farmers to increase its production. Again this might be facilitated if the economic benefit for the Base farmers is apparent. Thus, here we calculate the benefit expected from CBBP males used in Base populations.

The benefit arising from improved males used in the Base population requires tracing the gene expression of the progeny of these males and their descendants over time. The rate of genetic improvement of the rams supplied needs to be considered as well as the economic worth of this improvement and eventual additional costs need to be calculated and discounted to comparable values. Amer et al. (2007) developed a model to estimate the impact of sheep and beef improvement programs in commercial herds of Great Britain. Here we adapt Amer et al. (2007) model to estimate the impact of CBBP males in general herds. Again an Excel spreadsheet is used to model this case. In this model (Model 2) the number of additional males produced in CBBPs can be set as well as various other parameters. Rams from CBBPs may be used for one or more years depending on Base farmer decisions and ram survival. First progeny of such a mating is born in year = 0. For a given mating ratio, the total number of ewes mated can be calculated and for a given reproduction rate, the number of progeny born with genes from the improved rams can be calculated for each batch of rams.

The model calculates direct and maternal expressions of improved ram genes. A lamb born in year = 0 expresses directly 0.5 of the genes and if the lamb becomes a breeding female it also expresses genes in its progeny, these are maternal expressions. Since time flows and numbers of expressions are different, direct and maternal expressions are treated separately in the model. The probability of a ewe lamb to become a breeding female can be calculated from the ewe replacement rate and ewe survival. Replacement rate depend on reproduction rate (number of lambs born per ewe mated), age at first and last mating, survival of lambs to first mating and survival of ewes to last mating. For example 100 ewes mated 5 years with no mortality of progeny between birth and final lambing need 20 replacements. If reproduction rate is 1.0 then the probability of a lamb to become a breeding female and express its improved genes is 20/100 = 0.2 at each of its 5 lambing's. With other values for reproduction and survival rates these values change over lambing's. Amer et al. (2007) defines a vector w(k) for the maternal expressions at year k. If first mating/lambing is at 2 years of age then in the above example w(k) = (0 0 0.2 0.2 0.2 0.2 0.2).

The maternal expressed genes multiplied by the reproduction rate define the next generation of direct expressions. Thus, direct and maternal expressions of a single offspring and its descendants can be calculated recurrently over generations. Multiplying these expressions by the worth of annual genetic improvement and summing up over the number of progeny born each year gives total yearly income. First income from slaughter of first progeny will be in year 1. Additional costs may be included, for example additional cost of improved rams. Incomes and costs of successive years will be discounted to values of year 0. Discounted annual incomes, costs and benefits can be accumulated at a given planning horizon.

As previously, genetic and economic results are obtained setting various parameter values in the model. The direct expressed trait is SWT. The reference parameters used in this case are in Table 3, together with its justification or source.

2.6. Modelling the impact of more intense use of males produced by an ongoing CBBP (Strategy 3)

Artificial insemination (AI) allows using fewer males (*Case A*) and/or allows an increase in the number of females served with improved males (*Case B*). The economic impact of both possibilities will be considered under feasible AI program conditions.

Artificial insemination at CBBP level (Case A)

At CBBP level using fewer rams allows increasing the selection differential and consequently increasing the genetic progress. This case can be readily tested in Model 1 by adjusting the percentage of replacement rams selected in the Nucleus. Suppose we want to inseminate a proportion p of the ewes of a CBBP and suppose mrAI is the average number of ewes inseminated per AI ram. Then the average mating ratio (mr*) becomes mr* = mr x mrAI / (p x mr + (1 - p) x mrAI), where mr is the regular mating ratio without AI, and the percentage of replacement rams will be reduced by a factor of mr / mr*. For simplicity reproduction rate from natural mated and inseminated ewes is assumed to be the same (or its difference is accounted for in mrAI).

As a reference model we take the usual mating ratio of 30 females per ram (mr = 30) and with AI we take 200 females per ram (mrAI = 200). Further we assume 40% of all females in the CBBP are inseminated (p = 0.4) then the average mating ratio is 45.5 (mr* = 45.5) and the reference percentage of replacement rams selected of 0.40 (40 males selected for breeding out of 100 candidates) reduces to 0.40 x 30 / 45.5 = 0.26. The standardized selection differential would increase to 0.62 and the annual genetic progress (i x SD x h^2 / L) would increase to 0.14 kg/year (0.62 x 13.3 x 0.2 x 0.3 / 3.5). This genetic progress will be used as a consequence of the use of AI in this case.

Additional costs due to AI need to be considered. There will be implementation costs incurred at the start of the breeding program and operational costs incurred yearly. Implementation costs include for 400 ewes 2 artificial vaginas, 2 AI guns, part of the costs of various instruments (ultrasound, spectrophotometer, field microscope, speculum, and lighting source) and training of inseminators (400 $). Operation costs include for 400 ewes 2 injections of a prostaglandin analogue, AI straws, AI sheaths, antibiotics, inert packing powder, extender, lubricating gel and honorarium of inseminator (950 $).

In *Case A*, a proportion of (1-p) ewes are used in natural mating and therefore incurring in costs not related to AI. In the example of Strategy 1 the only cost considered was the additional value of improved rams. Thus, we maintain that additional cost for all rams, including the AI rams. The necessary parameter input data to test the genetic and economic impact of this AI program are summarized in Table 4.

Artificial insemination at Base level (Case B)

At the general flock level AI allows more extensive dissemination of genetic superiority. This case (*Case B*) can be analysed adjusting the mating ratio in Model 2. Suppose a proportion p of rams yearly purchased by Base farmers (not members of the CBBP) is used with AI at a rate of mrAI ewes per AI ram, the remaining rams are used at the regular rate mr. Then the adjusted mating ratio would be p x mrAI + (1 - p) x mr for the batch of rams including AI rams. Mating ratio of ram batches not including AI rams will be mr.

The number of ewes which can be inseminated will depend on the length of the breeding season and on the human and material resources which can be made available. Most Menz ewes ovulate in November and December; therefore an AI campaign would concentrate on that period. At present two insemination teams could work consecutively (or simultaneously if both have the necessary instruments) during 4 weeks (with breaks in between). Working 6 days a week and inseminating about 200 ewes per day, a total of 9600 ewes (2 x 4 x 6 x 200) could be inseminated in one season.

With a mating ratio of AI rams as in the previous case (*Case A*, mrAI = 200) the total number of AI rams used in a season would be 48 (9600/200). Thus, 48 rams out of the 200 available for dissemination will be used in the AI program (p = 0.24) the remaining 152 rams will be used at the regular mating ratio as in Strategy 2 (mr = 30). The total number of ewes mated with this ram batch will increase from 6000 (200 x 30) to 14160 (200 x (0.24 x 200 + (1 – 0.24) x 30)).

The costs involved in the AI campaign will be as in *Case A* adjusted to the number of ewes inseminated. In *Case A* for 400 ewes inseminated implementation costs were 400 $ and operational costs 950 $ then for 9600 ewes these figures increase to 9600 and 22800 $, respectively (Table 5). As in *Case A* regular ram costs have to be added, here again we consider all rams costing the same.

3. Results

3.1. Genetic progress and economic benefit from additional CBBPs (Strategy 1)

Genetic progress in the Nucleus is 0.11 kg/year accumulating 2.3 kg in the 20 years (Figure 1). Progress in the Base population follows progress in the Nucleus with a time lag which, as expected, becomes progressively constant at about two generations (7 years). The annual discounted benefit of both layers together increase over years up to about 15 years, when it becomes flat and then slowly diminishes (Figure 2). The accumulated discounted benefit and return to investment in the CBBP (Nucleus + Base) is highly advantageous (Table 6). Overall, for each $ invested in establishing one average CBBP, more than 5.2 $ were obtained with the assumptions made and parameters used in the reference model.

3.2. Genetic progress and economic benefit from more males produced by an ongoing CBBP (Strategy 2)

The impact of 200 males purchased annually from a reference CBBP and used in the Base population results in large discounted incomes (Table 7). Since the only cost considered in this model is an additional (to the meat price) 10% cost of improved rams, the return to investment is also very high. Only if improved rams would cost more than double their meat price (an unrealistic situation) this strategy would not return the investment. Annual discounted benefit in the Base population increases quickly the first 10 years or so (Figure 3). Only in the starting year when improved rams were paid an additional 10% and no improved lambs were sold, benefit would be negative. With this small extra cost and the spread of improved genes in the population the return to investment over time becomes very high.

3.3. Genetic progress and economic benefit from more intense use of CBBP males (Strategy 3)

Results at CBBP level (Case A)

More intense use of some males in the Nucleus of a CBBP allows reducing the number of males required for mating and therefore achieving a higher selection differential. In the reference system 40% of rams were selected on SWT and females were not selected, thus the standardized selection differential was (0.96 + 0.0)/2 = 0.48 and the resulting genetic progress and economic benefit are the ones shown in Table 6 and Figures 1, 2 and 3. Now suppose a CBBP with 1000 breeding females where AI is performed with 2 sires on 40% of the females (mrAI = 200, p = 0.4). Suppose also that natural mating on the remaining 600 females is at a ratio of 30 females per sire (mr = 30), then from a previous formula average mating ratio (mr*) becomes 45.5 and only 26% of males need to be selected among candidates instead of 40% (22 instead of 33 out of 83). The corresponding standardized selection differential is then 1.24 and average selection differential with no female selection is (1.24 + 0.0)/2 = 0.62. At the planning horizon SWT in the Nucleus would have raised 3 kg from 13.3 to 16.3 kg. The accumulated discounted benefit at the planning horizon is 50297 $ (Table 8) somewhat less than without AI (54550 $, Table 6). The return on investment at the Nucleus is much smaller than without AI (2.4 vs. 5.2). These results relate to the higher costs involved in the AI option (Table 8). Figure 4 shows that with this Strategy the benefit becomes positive at year 4 of the program.

Results at Base level (Case B)

More intense use of some males in the Base herds through AI allows reaching more ewes and more herds and therefore a higher dissemination of improved genes coming from a CBBP. We tested a CBBP providing 200 rams to general herds. From these 200 rams 48 were used with AI at a ratio of 200 ewes per ram whereas the remaining 152 at the regular rate of 30. In this case the total number of ewes mated with this ram batch would increase from 6000 to 14160 and the total number of lambs from this mating would increase from 7290 to 17204. The effect of such an AI program on the accumulated discounted income is very high but the increased costs make the benefit as well as the return to investment much less favourable than without AI (Table 9 vs. Table 7). Figure 5 shows that at year 6 of the program the discounted benefit of dissemination become positive.

4. Discussion

Genetic progress and economic impact were favourable for the 3 out- up-scaling strategies, in particular strategies aiming at replicating current CBBPs and strategies increasing the number of rams reaching Base flocks.

A current average Menz CBBP could increase genetically its SWT by 2.4 kg in 20 years. If AI is used in the Nucleus herds, genetic progress can reach 3.3 kg during the same period. These figures are largely independent of management interventions and climate changes which may occur during that period of time. A current CBBP could also provide many more rams for Base farmers and these rams could be used extensively on many more ewes with AI. The consequence of the genetic improvement and extended dissemination is a larger income for CBBP farmers and for their customers.

This is the expected outcome of out- up-scaling but a closer look at the results reveals that higher genetic progress and genetic dissemination due to AI implies very high increase in income but also very high increase in costs. In fact, in a CBBP, benefit (income – costs) and return to investment (income/costs) is larger in strategies without AI.

When comparing the benefit of a Nucleus + Base Strategy with and without AI, it is interesting to note that with AI the Base makes a positive difference whereas the Nucleus itself not. In other words AI in a Nucleus is important when average surplus rams are sold to Base farmers which are part of the community (as assumed in Strategy 1); otherwise AI is positive for Nucleus farmers in terms of genetic improvement but not so in terms of economic benefit. The problem is that Nucleus farmers involved in the AI program will not benefit from the economic success at Base farmer level unless the community (Nucleus + Base) arranges a fair distribution of benefits; or if the Nucleus farmers can get more than a 10% additional price for their selected young rams.

Low input farmers operate on low risk, their little cash must be available for immediate crucial expense needs, therefore technologies which allow higher benefit but have high costs might be attractive to commercial farmers or companies but might imply an unbearable cash risk to low input farmers, unless this risk is taken externally. There are two options here. Either public institutions take this risk, but they are rewarded to see breeding programs aligned with their national policies. Alternatively, like in cattle breeding, this opens up the door to privates for new business models in the area of animal breeding.

In the present AI modelling it is assumed that AI rams are average selected rams, which are supposed to be of similar genetic merit as other selected rams for breeding. In advanced breeding programs, with comprehensive performance and genealogical records, higher breeding value accuracy can be obtained and further selection pressure could be applied. In fact AI facilitates pedigree recording and therefore contributes to improve breeding value accuracy. This would result in additional genetic progress and increased benefit at the same cost. Another aspect which makes AI programs attractive is a better prevention of disease spreading.

There are several assumptions on parameters which can be easily tested with upper and lower figures. For example breeding program duration (T), planning horizon (H) and discount rates (r) have great impact on results. T and H were set at maximum values (20 years) and r at 7%, such input is typical for long term planning and national interest situations where benefits are expected to be sustained and opportunity cost is low. Shorter planning horizons and higher discount rates reduce benefits. For example for Strategy 1 if H = 10 and r = 0.14 return on investment becomes 2.4, compared to the reference result of 5.2. AI based strategies would be affected even more with small H and large r's.

Another key result is that AI used only at general flock level that is, used only as a dissemination tool, is hardly justified (return on investment = 1.6). This is because the costs involved are not compensated with the genetic improvement disseminated. The assumption here was that AI rams follow the regular improvement rate of the Nucleus of 0.11 kg/year. If this rate rises to 0.14 kg/year, as it would with AI at the Nucleus level, then return on investment also rises from 1.6 to 2.0.

Genetic progress and economic benefit was calculated considering SWT as unique breeding objective, other traits are usually also of interest and would be considered either formally or allowing more room for visual selection. Also costs may differ for specific communities, but we expect the general findings of this study to hold over most practical situations.

5. Conclusion

Out- and up-scaling sheep CBBPs in Ethiopia are warranted with high returns to the necessary investments, in particular by replicating already operating CBBPs and by increasing the number of breeding males supplied to general herds. Adding AI would further increase genetic progress and dissemination but would require consideration of substantial additional costs.

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Figure

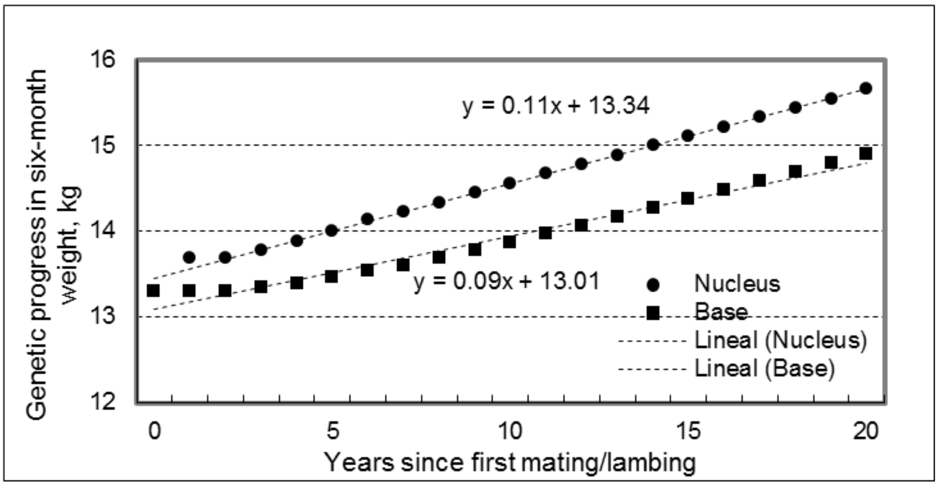

Figure 1: Genetic progress in six-month weight (SWT) in the Nucleus and Base herds of a CBBP. Both layers started with the same initial SWT of 13.3 kg.

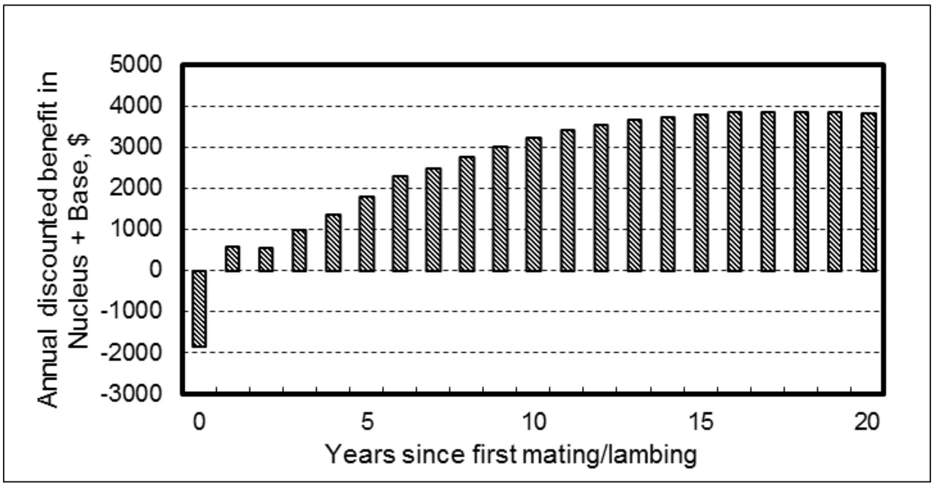

Figure 2: Total (Nucleus + Base herds of a CBBP) discounted annual benefit over the planning period.

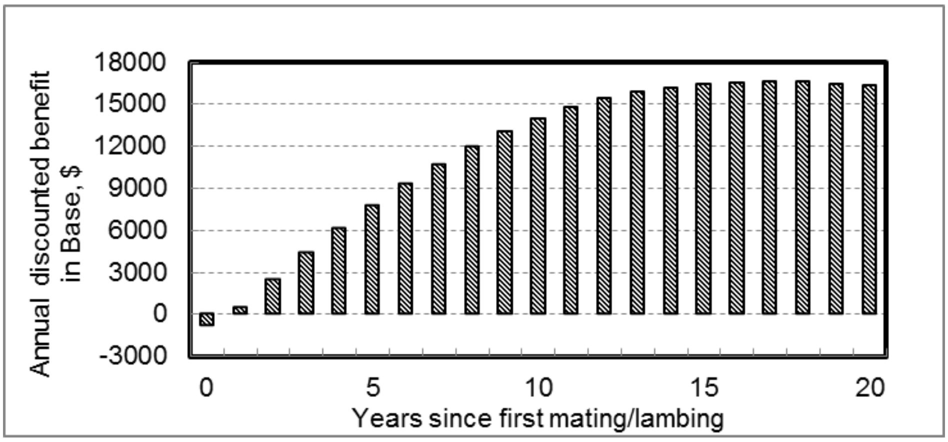

Figure 3: Annual discounted benefit in Base herds due to improved genes from CBBP rams.

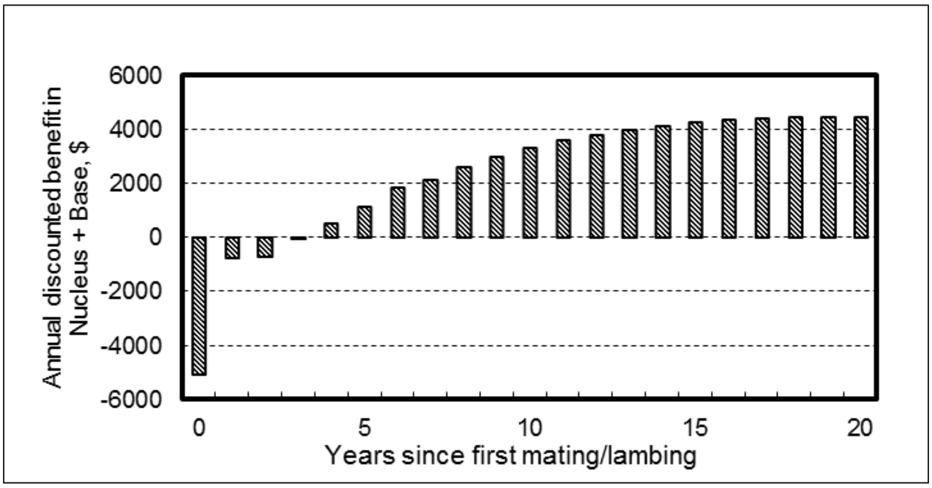

Figure 4: Annual discounted benefit in Nucleus and Base herds of a CBBP when AI is used in the Nucleus.

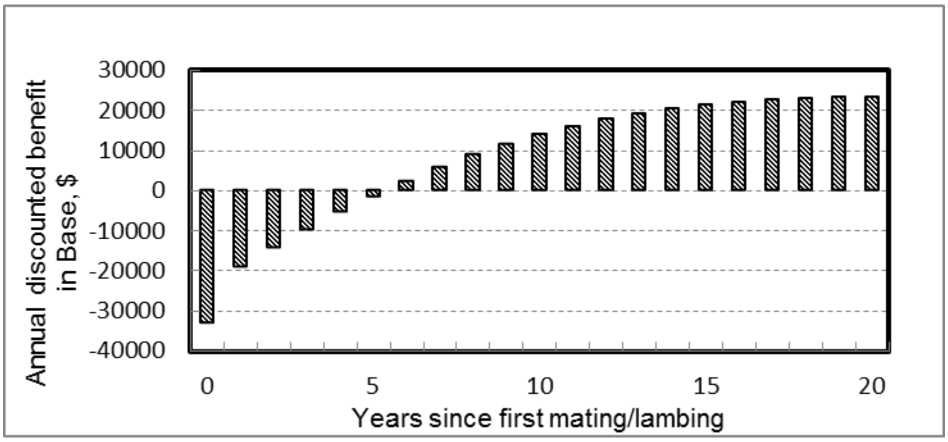

Figure 5: Annual discounted benefit in Base herds when AI is used.

Table 1: Summary of out- and up-scaling strategies analysed.

Strategy tested	Model used	Main features in Nucleus herds	Main features in Base herds	Impact measured
Strategy 1. Reference CBBP	Model 1	Using current rate of genetic progress	Using current number of rams distributed (32)	Nucleus + Base
Strategy 2. Increasing the number of rams for distribution to Base	Model 2	Using current rate of genetic progress	Using a proposed number of rams distributed (200)	Base only
Strategy 3 Case a. More intense use of rams in Nucleus (AI)	Model 1 adjusting mating ratio in Nucleus	Using increased rate of genetic progress due to AI on 40% of ewes	Using current number of rams distributed (32)	Nucleus + Base
Strategy 3 Case b. More intense use of rams in Base (AI)	Model 2 adjusting mating ratio in Base	Using current rate of genetic progress	Using a proposed proportion of rams with AI (48/200)	Base only

Table 2: Input parameter in reference model (Model 1 Strategy 1).

Parameters in Nucleus	Input	Justification or source
Nr of ewes	1000	Average Menz CBBPs
Annual reproduction rate at SWT age	1.22	Average Menz (1.5 lambings x 0.9 conception x 0.9 survival)
Initial average SWT, kg	13.3	Average Menz
CV of SWT	0.20	Preliminary unpublished estimations
Replacement rams selected on SWT	0.40	Average Menz
Replacement ewes selected on SWT	1.00	Assuming no female selection pressure
Heritability of SWT	0.30	Preliminary unpublished estimations
Additional costs		
Implementation, first year, $	950	Detailed in text (400 + 20 + 200 + 290 + 40)
Operation, annually, $	909	Detailed in text (354 + 555)
Economic parameter		
Value of 1 kg live weight at SWT, $	3.29	Given that market price of a lamb weighing 13.3 kg is 43.7 $
Planning horizon, years	20	Long term plan
Discount rate	0.07	Used in literature for projects of national interest
Parameters in Base		
Nr of young rams from Nucleus	32	This is 40 - 8 in average Menz CBBP
Mating ratio, nr of ewes / ram / year	30	Menz field information
Annual reproduction rate at SWT	1.22	As in Nucleus
Initial average SWT, kg	13.3	As in Nucleus
Additional cost of an improved ram, $	4.38	For example 10% more than meat value (13.3 kg x 3.29 $/kg x 0.1)

SWT: Six-month weight.

Table 3: Input parameter in the reference model (Model 2 Strategy 2).

Parameter in Base	Input	Justification or source
New Nucleus rams used in Base annually	200	Considered reasonable in average CBBP
Age of rams at last mat/lambing (max = 5)	3	Menz field information
Annual survival of rams in Base	0.80	Menz field information
Ewes mated per ram in Base	30	As in Model 1
Age of ewes at last mat/lambing (max = 8)	6	Menz field information
Annual survival of ewes from 1-year on	0.90	Menz field information
Annual lambs born per ewe in Base	1.5	As implied in Model 1
Survival of lambs to SWT in Base	0.81	As implied in Model 1
Direct annual genetic progress in SWT, kg	0.110	As implied in Model 1
Economic value of SWT, $/kg	3.29	As in Model 1
Additional cost of CBBP ram, $	4.38	As in Model 1
Years of improvement in Nucleus (max = 20)	20	Assuming a continuous breeding program
Planning horizon (max = 20), years	20	As in Model 1
Discount rate	0.07	As in Model 1

SWT: Six-month weight.

Table 4: Specific parameter input when the breeding program in a CBBP includes AI in the Nucleus (Model 1 Strategy 3 Case a).

Parameters in Nucleus	Input	Justification or source
Proportion of CBBP ewes inseminated	0.4	For example 400 of 1000 ewes in a CBBP
Mating ratio with AI	200	For example 2 AI rams used on 400 ewes of a CBBP
Additional costs due to AI		
Implementation, first year, $	400	Detailed in text
Operation, annual, $	950	Detailed in text

Table 5: Specific parameter input when a proportion of CBBP rams are used with AI in the Base (Model 2 Strategy 3 Case b).

Parameters in Base	Input	Justification or source
Proportion of CBBP rams used in Base with AI	0.1	For example 20 out of 200 CBBP rams used in Base with AI
Mating ratio with AI	200	For example 4000 ewes with 20 rams
Additional costs due to AI		
Implementation, first year, $	9600	Detailed in text
Operation, annual, $	22800	Detailed in text

Table 6: Genetic progress and economic benefit in a CBBP with current average characteristics. Results at planning horizon (H = 20) and program duration (T = 20) for the reference model.

Results	Nucleus	Base	Nucleus + Base
Final trait level, kg	15.7	14.9	
Annual income, $	9612	6172	15784
Discounted annual income, $	2484	1595	4079
Accumulated discounted income, $	47664	20011	67674
Annual costs, $	909	140	1049
Discounted annual costs, $	235	36	271
Accumulated discounted costs, $	11499	1625	13124
Discounted annual benefit, $	2249	1559	3808
Accumulated discounted benefit, $	36165	18386	54550
Return on investment, $/$	4.1	12.3	5.2

Table 7: Impact on economic benefit of 200 CBBP rams used in Base herds. Results at planning horizon (H = 20) and program duration (T = 20) for the reference model.

Results	Base
Accumulated discounted income, $	250647
Accumulated discounted cost, $	10156
Accumulated discounted benefit, $	240491
Return on investment, $/$	24.7

Table 8: Genetic progress and economic benefit in a CBBP with AI in the Nucleus. Results at planning horizon (H = 20) and program duration (T = 20) for the reference model.

Results	Nucleus	Base	Nucleus + Base
Final trait level, kg	16.3	15.4	
Annual income, $	12285	7914	20199
Discounted annual income, $	3175	2045	5220
Accumulated discounted income, $	60657	25658	86315
Annual costs, $	2768	140	2908
Discounted annual costs, $	715	36	752
Accumulated discounted costs, $	34392	1625	36017
Discounted annual benefit, $	2459	2009	4468
Accumulated discounted benefit, $	26264	24033	50297
Return on investment, $/$	1.8	15.8	2.4

Table 9: Impact on economic benefit of 200 CBBP rams used in Base herds, including 24 rams used with AI. Results at planning horizon (H = 20) and program duration (T = 20).

Results	Base
Accumulated discounted income, $	451182
Accumulated discounted cost, $	284100
Accumulated discounted benefit, $	167082
Return on investment, $/$	1.6

AUTHOR DECLARATION TEMPLATE

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

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