Scotland's Rural College

Is cross-breeding with indigenous sheep breeds an option for climate-smart agriculture?

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Manuscript: Is cross-breeding with indigenous sheep breeds an option for climate-smart agriculture?

1. Introduction

Livestock support the livelihoods of about 600 million people in developing countries, and make important contributions to food security (Thornton 2010). The impacts of climate change pose a threat to livestock production and livelihoods (Thornton *et al.* 2007). Livestock also contribute a significant proportion of agricultural greenhouse gas (GHG) emissions, mostly due to ruminant enteric fermentation and emissions in feed production processes (Gerber *et al.* 2013a). Climate-smart agriculture aims to improve food security by increasing productivity and producer incomes, strengthening resilience to climate change, and reducing GHG emissions (FAO 2013). Improved animal genetics has frequently been identified as a climate-smart approach that could increase animal and herd productivity while also improving adaptation to and mitigation of climate change (Hoffmann 2010; Gerber *et al*. 2013b; Porter *et al*. 2014). While the benefits of genetic improvement for achieving these objectives have been well documented in intensive production systems (e.g., Shook 2006; Sosnicki and Newman 2010), there have been few studies on the effects of breeding with indigenous animal genetic resources in more marginal production systems, where the adaptive traits of indigenous breeds can be expected to play a significant role in supporting resilience to climate change (Thornton *et al.* 2007).

Livestock production contributes about 8% of Mongolia’s gross domestic product, and is the main source of livelihoods for about 30% of Mongolian households (Dagvadorj *et al*. 2014). The potential impacts of declining precipitation on grassland productivity, an increase in the number of high temperature days on sheep live weight gain, and an increase in the frequency and severity of severe cold events following summer drought (known as *dzud* events) are major concerns (Dagvadorj *et al.* 2014). The Mongolian government’s livestock development and climate change policies are responding to these challenges by aiming to improve livestock productivity and the resilience of livestock production systems to climate change, and by identifying GHG mitigation opportunities that have synergies with sector and adaptation policy objectives (GoM 2010, 2011, 2015). While there is no specific national breeding policy, the National Livestock Program provides subsidized credit for establishment of core flocks for the conservation of indigenous breeds, and some local governments have funded herders to purchase breeding animals from these flocks for use in cross-breeding (MIA 2014).

This study aims to explore the synergies and trade-offs between production, adaptation and mitigation objectives of genetic improvement with indigenous sheep breeds in Mongolia. Using a unique dataset on the live weights of 990 sheep with two different genetic compositions (indigenous Mongol short-tail sheep and cross-breeds of Mongol short-tail and Barga breed), together with results of household questionnaires on management practices, we examine the contribution of breed to production, adaptation to winter cold, and mitigation of GHG emissions. Live weight of animals is taken as an indicator of productivity. Live weight loss during the winter season is taken as an indicator of adaptation to winter cold. GHG emission per kg live weight sold at the flock level is taken as an indicator of the potential benefits of cross-breeding for the mitigation of global climate change. A statistical modelling approach is used to distinguish the effects of breed from the effects of management practices on sheep live weight and weight loss.

2. Data and methods

2.1 Study area, breeds and management practices

Most Mongolian sheep breeds are fat tail breeds, which store fat in their tails to draw on during the period of energy deficit in winter and spring. In general, Mongolian fat tail sheep breeds can be characterized as short- or wide-tailed. The vast majority of sheep are short-tailed Mongol breed. Nineteen other breeds have been identified, one of which is the Barga breed. Barga sheep are also short-tailed, but have a longer, thinner tail and a longer body, and are valued for their higher live weight and resistance to cold (Binye 2012). Both breeds are raised primarily for their meat and fat, with wool as a secondary product. Studies report no significant difference in fertility parameters such as lambing rates between the two breeds (Binye 2012).

Conservation flocks of Barga sheep have been established in Khulunbuir district, Dornod province. Many households from neighbouring Bayan-ovoo district have purchased Barga rams to cross-breed with Mongol breed ewes. Surveys were conducted in Bayan-ovoo district, and in Sant district, Uvurkhangai province, where herders raise the Mongol breed. Both study districts are located in the typical steppe vegetation zone. Sheep graze during the daytime, at locations between 2 and 10 km from the herding camp, and are corralled at night. During the summer and autumn months, as forage resources near a herding camp become depleted, herders move their camp, commonly making 3 or 4 moves during the summer and autumn seasons. In Sant and Bayan-ovoo districts, from 1991 to 2010 average daily temperatures from October to April were -6.27ºC and -8.98ºC, respectively. Sheep typically lose weight during this period, when forage resources are limited. During winter and spring, small amounts of hay and wheat chaff are fed to weak animals and pregnant ewes. Sheep serve as a store of value in a context of high monetary inflation and risks related to weather and disease are high, so sheep are generally raised until the age of 2-3 years. Market prices are set per kg live weight, and do not distinguish between age or body condition of the sheep sold. Sales mostly occur at the end of the autumn season, when sheep are at their maximum weight, though some are sold in the months that follow, especially if herders judge that winter forage resources are limited.

2.2 Data collection

Households in Bayan-ovoo were identified whose flocks have a mixture of the Mongol and Barga breed genetics. These are referred to as ‘improved’ flocks. Households and flocks in Sant district were selected to represent the Mongol breed with no admixture of Barga or other genetics. For each flock type, 15 households were selected following a stratified random sampling procedure. At the level of individual sheep flocks, sheep were categorized by age (i.e., <12 months, 12-24 months, >24 months) and physiological state (i.e., castrated male, intact male, and female). In each flock, 33 sheep were sampled with individuals of each age/sex class randomly selected roughly in proportion to their presence in the flock.

Sheep achieve their maximum weight in late autumn, and their minimum weight before grass begins to regrow in early May of each year. Each sampled sheep was weighed twice, once in late autumn (between 22 November and 1 December 2014) and once in late spring (between 15 April and 25 April 2015). All sheep were weighed in the morning before going to pasture using walk-on scales. During the spring weighing, one previously weighed sheep was no longer in the flock and was replaced with another sheep of the same age and physiological state selected at random from the flock. A total of 990 sheep were weighed. A structured questionnaire was also used to collect data on household and flock characteristics (i.e., age, sex and years of herding experience of the main shepherd, flock size and structure, numbers and structure of off-take, number of introduced rams), management practices including feeding (i.e., hay, supplement and salt availability), grazing (i.e., number of camp moves and grazing distance in summer-autumn and access to reserve pasture in winter), veterinary healthcare (i.e., use of government-provided vaccinations, treatment for internal parasites and annual total expenditures on veterinary medicines), and parameters used in the estimation of GHG emissions.

2.2 Modelling framework for determinants of live weight and weight loss

Data from the survey of sheep and the household survey were used to explore the determinants of autumn live weight and winter-spring live weight loss. A mixed level modelling framework was chosen to control for the influence of household heterogeneity across the sample. A random intercept model, using households as the level-1 nested clusters, was estimated to examine both variance at household level and the influence of explanatory variables on determining sheep live weight in late autumn and weight loss between late autumn and late spring. Categorical variables were set as dummies, using the base outcome class as reference. Estimation was conducted using Stata version 14 (Stata Corp., 2014).

2.3 Modelling GHG emissions

The IPCC Tier 2 methods were used to estimate methane (CH_4) emissions from enteric fermentation and manure management, direct nitrous oxide (N_2O) emissions from manure management and pasture deposit and nitrogen (N) losses from volatilization (IPCC 2006). Consistent with the IPCC guidelines, indirect N losses due to leaching were not estimated, as evaporation greatly exceeds precipitation for most of the year in the study region. For estimation of CH_4 emissions from enteric fermentation, the surveys provided data on live weight and live weight gain at different ages, daily grazing distance, and prevalence of twin births. Digestible energy of typical steppe forage was estimated using data in Sun et al. (2007). Wool production estimates used data reported in Binye (2012). For emissions from manure management, estimates of nitrogen (N) excretion and proportion of N excretion in different management systems derived from Holst *et al.* (2007), with the former scaled by sheep live weights from the survey. All other variables used appropriate default values from IPCC (2006). All GHGs were converted to carbon dioxide equivalent (CO_2e) using the most recent estimates of their global warming potential (IPCC 2013).

Sheep were categorized into 18 types based on breed (improved vs. Mongol), physiological state (intact male, castrated male, female) and age (<12 months, 12-24 months, >24 months). Annual GHG emission factors were estimated separately for each type of sheep, except for intact males aged 12-24 months of the Mongol breed, which were not sampled during weighing. To compare the intensity of GHG emissions between flocks with Mongol and improved sheep (kg CO_2e per kg live weight sold per flock), we first calculated total annual emissions from the flock. For sheep retained throughout the year, total emissions were calculated as the sum of the product of the annual GHG emission factor for each type of sheep and the number of sheep of each type retained in the flock. Data was not collected on the date of sale of each sheep. For autumn sales it was assumed that sheep were sold on October 15th, and for winter sales it was assumed sheep were sold on January 15th, which were the median dates of the periods in each season during which herders indicate sales are made. The annual GHG emission factors were then adjusted for the number of days that sheep of each type were estimated to be present in the flock. No mortality was reported in either the autumn or spring survey, so adjustments for mortality were not made. For each type of sheep, GHG emissions attributable to live weight production were allocated using the economic allocation method, assuming a live weight price of MNT 1481 per kg and a wool price of MNT 3000 per kg. GHG emissions allocated to live weight sales averaged 95% (s.d. 2%) for different age/sex classes of sheep. All parts of slaughtered sheep are used, so live weight (rather than carcass weight) was taken as the denominator in the measure of GHG emission intensity. For sheep sold in autumn, live weight was estimated as 95% of the mean weight for sheep of each type recorded in the autumn survey. For sheep sold in winter, live weight at sale for each type of sheep was estimated using the mean autumn and spring weight data for each type of sheep, assuming a linear decrease in weight from the date of autumn weighing to January 15th. Total live weight sold from each flock was calculated as the mean live weight of each type of sheep at sale in each season multiplied by the number of sheep of each type sold in each season. The statistical significance of differences in weights, weight loss and GHG emission factors and flock emission intensity between breeds were tested using a two-tailed t-test (p=0.05).

3. Results and discussion

3.1 Flock characteristics

Fifteen improved flocks and 15 Mongol breed flocks were sampled. In autumn 2014 and spring 2015, the average size of improved flocks was significantly larger than the average size of Mongol breed flocks (Table 1). The structure of improved flocks was similar to the structure of Mongol breed flocks. There was little difference in average off-take rates between the two flock types, but off-take from Mongol flocks had a slightly younger age structure than from improved flocks. No rams from improved flocks were sold, which is consistent with the breeding objectives of owners of improved flocks.

Table 1: Flock size and structure of off-take, descriptive variables

	Improved	Mongol
Average sheep per household autumn	596.8 (341.50)	262.67 (132.20)
Average sheep per household spring	561.00 (301.78)	245.73 (122.33)
Average number of sheep sold per household per year	139.53 (88.31)	69.60 (48.82)
Average off-take rate*	19.11% (6.56%)	22.01% (8.15%)
Age structure of off-take:		
<12 months as % of total off-take	4.60% (12.16%)	6.73% (11.62%)
1-2 years as % of total off-take	39.75% (12.29%)	35.49% (25.61%)
2-3 years as % of total off-take	55.65% (18.58%)	52.46% (29.35%)
Sex structure of off-take:		
Intact males as % of total off-take	0% (0%)	7.83% (16.31%)
Castrated males as % of total off-take	77.51% (9.16%)	60.37% (16.73%)
Females as % of total off-take	22.49% (9.16%)	31.80% (11.41%)
Seasonal structure of off-take:		
Off-take in summer-autumn	73.16% (15.49%)	71.02% (26.04%)
Off-take in winter-spring	26.84% (15.49%)	28.98% (26.04%)

Figures in brackets are standard deviations. *Calculated as the number sold divided by the total number kept in the year.

3.2 Sheep live weights and winter weight loss

Autumn weight was significantly higher (p<.05) across all sex-age categories for sheep in improved flocks compared to Mongol flocks (data not shown). Winter-spring weight loss was also significantly less (p<.05) for improved flocks versus Mongol flocks across all sex-age categories (Table 2). Figure 1 shows the quartiles for live weights in autumn and spring, compared across breed. Starting median weights for sheep in improved flocks were higher, at 55.2 kg, compared to 54 kg for the Mongol breed. For the Mongol breed, median weight loss was higher at 16 kg, compared to about 11 kg for sheep from improved flocks.

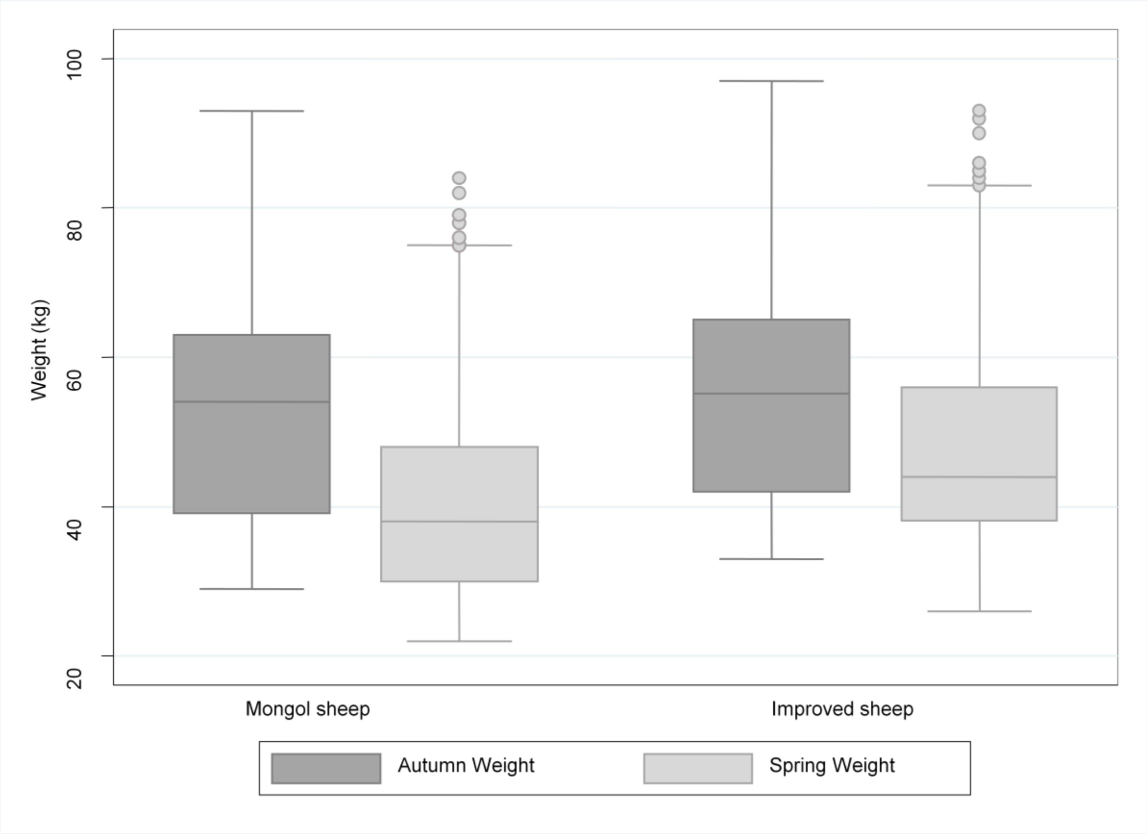
Table 2: Mean and standard errors of winter-spring weight loss (kg) for Mongol and improved breeds, stratified by sex and age

	Improved	Mongol
Male uncastrated<12 mths	-3.99 (0.37)^{a}	-9.40 (0.65)^{b}
Male uncastrated 12-24 mths	-5.65 (0.34)^{a}	-
Male uncastrated >24 months	-4.89 (0.40)^{a}	-10.29 (0.65)^{b}
Male castrated <12 months	-5.30 (0.58)^{a}	-7.67 (0.36)^{b}
Male castrated 12-24 months	-8.00 (1.58)^{a}	-9.19 (0.34)^{b}
Male castrated >24 months	-8.93 (0.88)^{a}	-7.12 (0.36)^{b}
Female <12 months	-4.36 (0.37)^{a}	-8.82 (0.36)^{b}
Female 12-24 months	-12.20 (0.37)^{a}	-17.24 (0.36)^{b}

Female >24 months	-14.19 (0.36) ^{a}	-18.96 (0.36) ^{b}

Different letters in rows indicate significant difference ($p<0.05$).

Figure 1: Boxplot of autumn weights and spring weights by breed (kg)



3.3 Factors affecting autumn weight and winter weight loss

Table 3 shows the maximum likelihood estimates for the effect of improved breed and other variables on autumn weight and winter-spring weight loss. Both regressions explain a significant amount of variance on each weight variable, with R^2 values of between 0.55 for winter-spring weight loss and 0.84 for autumn live weights. The signs and size of effect for age on autumn weight are as expected, with older sheep estimated to have the largest effect (in kg) on autumn weight. The changes in weight loss across the different age categories are low, with sheep aged 12-24 months and >24 months losing around 4.5 to 5 kg, respectively, relative to lambs.

Table 3: Maximum likelihood estimates for autumn live weights and winter-spring weight loss (standard errors in brackets)

Variables	Autumn Live Weight	Winter-spring weight loss

Constant	α	35.78***	10.93***
		(3.286)	*(1.101)*
Age *(reference class <12 months)*			
12-24 months	β_1	16.93***	4.612***
		(0.402)	*(0.275)*
>24 months	β_2	30.65***	4.997***
		(0.405)	*(0.277)*
Breed *(reference class: Mongol breed flock*)			
Improved flock	β_3	4.042***	-4.146***
		(1.123)	*(0.358)*
Sex *(reference class: male intact)*			
Castrated male	β_4	4.159***	-2.733***
		(0.603)	*(0.412)*
Female	β_5	-2.383***	3.291***
		(0.595)	*(0.407)*
Use of free vaccinations from government (Yes 1/ No 0)	β_6	0.700	-2.884***
		(2.530)	*(0.807)*
Is a shed used for housing in winter (Yes 1 / No 0)	β_7	-1.034	0.0506
		(1.682)	*(0.537)*
Use of internal parasite treatment (Yes 1 / No 0)	β_8	-0.175	1.972***
		(1.511)	*(0.482)*
Expenditure on veterinary services (MNT/head)	β_9	-0.0002	-0.0005
		(0.0009)	*(0.0003)*
Hay available per flock (kg/head)	β_{10}	0.020	0.005
		(0.042)	*(0.014)*
Supplementary feed available per flock (kg/head)	β_{11}	1.481**	0.276
		(0.585)	*(0.187)*
Grazing distance from campsite in summer (km)	β_{12}	-0.061	-0.325***
		(0.302)	*(0.0963)*
$\overline{\psi}$		2.468	0.568
		(0.361)	*(0.160)*
$\sqrt{\theta}$		5.163	3.539
		(0.118)	*(0.081)*
R^2		0.837	0.559

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

For both regressions, breed is strongly significant and positive for autumn live weights, and negative for winter-spring weight loss. Consequently, the model predicts that, all other things being equal, an improved breed would have about 4 kg less weight loss compared to the

Mongol breed. A Wald test found that in both cases we could strongly reject the null hypothesis that coefficients for breed were both zero ($p<0.01$). Differences also occur in terms of the physiological state of sheep. Compared to intact males, castrated males would be 4.2 kg heavier and would lose around 2.7 kg less weight. Females were lighter than intact males and, in addition, would expect to lose around 3 kg more than intact males.

Several management variables proved significant in determining weights for both breeds. Feeding supplements provides a marginal weight increase compared to non-supplemented flocks in the autumn. This effect does not appear to be significant in terms of mitigating weight loss in the winter-spring period, most likely because of the small amounts of feed available to each sheep during this period. Use of government-provided vaccinations is associated with a reduction in the amount of weight loss by around 3 kg compared to those not using these services. When combined with parasite treatment, the magnitude of these effects is larger than the effect of adopting improved breeds.

A longer grazing distance from the campsite is also associated with less weight loss. This is most likely due to improved forage availability and intake in locations further from camp sites, and may reflect differences in shepherding practices among herders. Other variables reflecting grazing practices were not significant. Using medicines to control internal parasites is associated with greater weight loss. However, this variable may be a proxy for the effect of parasitic infection on dictating weight loss, thus requiring the need to use medicine as a reactive step. This effect equates to a loss of around 2 kg per head. Finally, the random part of the equations shows the effect of the random intercept $\sqrt{\phi}$ and the variance between households $\sqrt{\theta}$ on weights. This latter variable indicates that the standard deviation between household weights in autumn is 5.16 kg and 3.54 kg in spring, which suggests considerable scope for increasing live weights by improving management at household level.

Most sheep are sold in autumn, although 26%-29% are sold in winter (Table 1). Since sheep in the study region are sold at a fixed price per kg live weight, higher autumn weights and lower winter-spring loss translate into direct financial benefits of breed adoption for herders. Lower rates of weight loss may also imply resilience of the benefits of breeding to winter cold. Average daily temperatures from October 2014 to April 2015 were 1.68ºC and 2.59ºC higher than the long-term average in Sant and Bayan-ovoo, respectively. Thus, these findings cannot be assumed to apply in years with particularly severe or prolonged cold in winter and spring.

3.4 GHG emission intensity

Annual GHG emission factors (kg CO_2e head^{-1} year^{-1}) for sheep of each age/sex class are shown in Table 4. Comparing across ages, annual emissions per head increase dramatically as age increases. This is mainly due to increased feed intake requirements with live weight and age. Annual emission factors for mature females are generally higher than for males because of additional energy needed for pregnancy and lactation. Comparing across breeds, improved sheep have a significantly higher emission factor for 6 out of the 8 types of sheep compared. This is due to higher feed intake requirements associated with greater average live weight of improved sheep in each age/sex class.

Table 4: Mean and standard error of annual GHG emission factor (kg CO_2e head^{-1} year^{-1}) for Mongol and improved breeds, stratified by sex and age

	Improved	**Mongol**
Male intact <12 months	179.47 (2.15) ^{a}	176.42 (1.28) ^{a}
Male intact 12-24 months	328.78 (10.48)	(not estimated)
Male intact >24 months	387.37 (10.22) ^{a}	382.06 (5.94) ^{a}
Male castrated <12 months	181.75 (2.02) ^{a}	165.34 (1.35) ^{b}
Male castrated 12-24 months	350.31 (3.63) ^{a}	292.70 (3.13) ^{b}
Male castrated >24 months	445.53 (4.78) ^{a}	389.43 (5.44) ^{b}
Female <12 months	174.94 (1.60) ^{a}	160.71 (1.29) ^{b}
Female 12-24 months	360.89 (3.00) ^{a}	339.43 (2.95) ^{b}
Female >24 months	403.02 (3.41) ^{a}	381.61 (3.28) ^{b}

Different letters in rows indicate significant difference ($p<0.05$).

The GHG emission intensities of live weight (LW) sales from improved and Mongol flocks were estimated at 23.82 $kgCO_2e\ kgLW^{-1}$ (s.d.:10.61) and 22.55 $kgCO_2e\ kgLW^{-1}$ (s.d.:11.92), respectively, indicating no significant difference between the two flock types ($p<0.05$). For both flock types, GHG emissions from sheep retained in the flock contributed about 86% of total emissions, and females accounted for more than half of total emissions from sheep that were not sold in the year. Castrated males account for the majority of sales by number of sheep and live weight sold. Although compared to Mongol sheep, improved sheep in all age-sex classes have a higher live weight, whether sold in autumn or winter, annual emissions per head are also higher. In particular, castrated males over 12 months old account for about 74% and 60% of average live weight sold per improved and Mongol flock, respectively. However, the annual emission factors for improved sheep in these age-sex classes are about 20% and 14% higher than for comparable Mongol sheep, while the average live weight of these sheep is 14% and 11% higher than for comparable Mongol sheep. Thus, the GHG impact of breeding depends significantly on the age and sex structure of flocks and the off-take rate. Reductions in the average age of sheep raised in flocks of either breed or increases in off-take rate would have significant impacts on the GHG intensity of sheep production.

In our study, methane emissions from enteric fermentation accounted for between 83% and 89% of total GHG emissions for each type of sheep of both breeds. The population-weighted average enteric fermentation emission factors for Mongol and cross-bred sheep (i.e. 7.39 and 8.32 $kgCH_4\ head^{-1}\ year^{-1}$) are higher than both the Tier 1 emission factors in IPCC (2006) and the Mongolian Tier 2 emission factors (Dagvadorj *et al.* 2009), mainly reflecting higher annual average live weight in our survey. Our estimates of the GHG intensity of sheep production are also higher than estimates reported in a global study, which assumed a lower global warming potential for methane, lower weights and higher off-take rates than in our study (Gerber *et al*. 2013a). Sensitivity analysis showed that the IPCC (2006) enteric fermentation model is most sensitive to the digestibility of feed, the methane conversion factor (*Ym*), weight, and a coefficient relating metabolic live weight to net energy requirements for maintenance (Cf_i). Of these variables, field data was only available for weight. Further studies are required in Mongolian conditions to determine appropriate values of other sensitive parameters in the Tier 2 enteric fermentation model.

4. Conclusion

Climate-smart agriculture aims to improve economic outcomes for producers, while promoting both adaptation to and mitigation of climate change (FAO 2013). This case study from Mongolia suggests that breeding with indigenous sheep can be a climate smart agriculture option. Barga-Mongol cross-breeds have a higher weight at a given age than Mongol sheep, both in autumn and the end of the winter-spring period. This implies financial benefits for herders and resilience of the improved breed to winter cold. There was no significant difference in the GHG emission intensity of sheep production at the flock level, indicating that production benefits could be achieved without increased impacts on global climate change. The study was undertaken in a year with above average winter-spring temperatures, so these results cannot be taken to apply to years with severe and prolonged cold in winter-spring. Furthermore, the results may not apply to other indigenous breeds with different adaptive traits and growth characteristics.

Live weight and live weight gain are key determinants of the benefits of cross-breeding identified in this study. However, breed is not the only factor influencing live weight. In particular, animal health practices, herders' daily grazing management practices, and to a lesser extent the availability of supplementary feed, were identified as management variables that also impact on weight and weight loss. This suggests that programmes to promote climate smart practices in extensive grazing systems should consider an integrated approach to improving animal management and marketing, rather than promoting single practices, such as cross-breeding with indigenous breeds.

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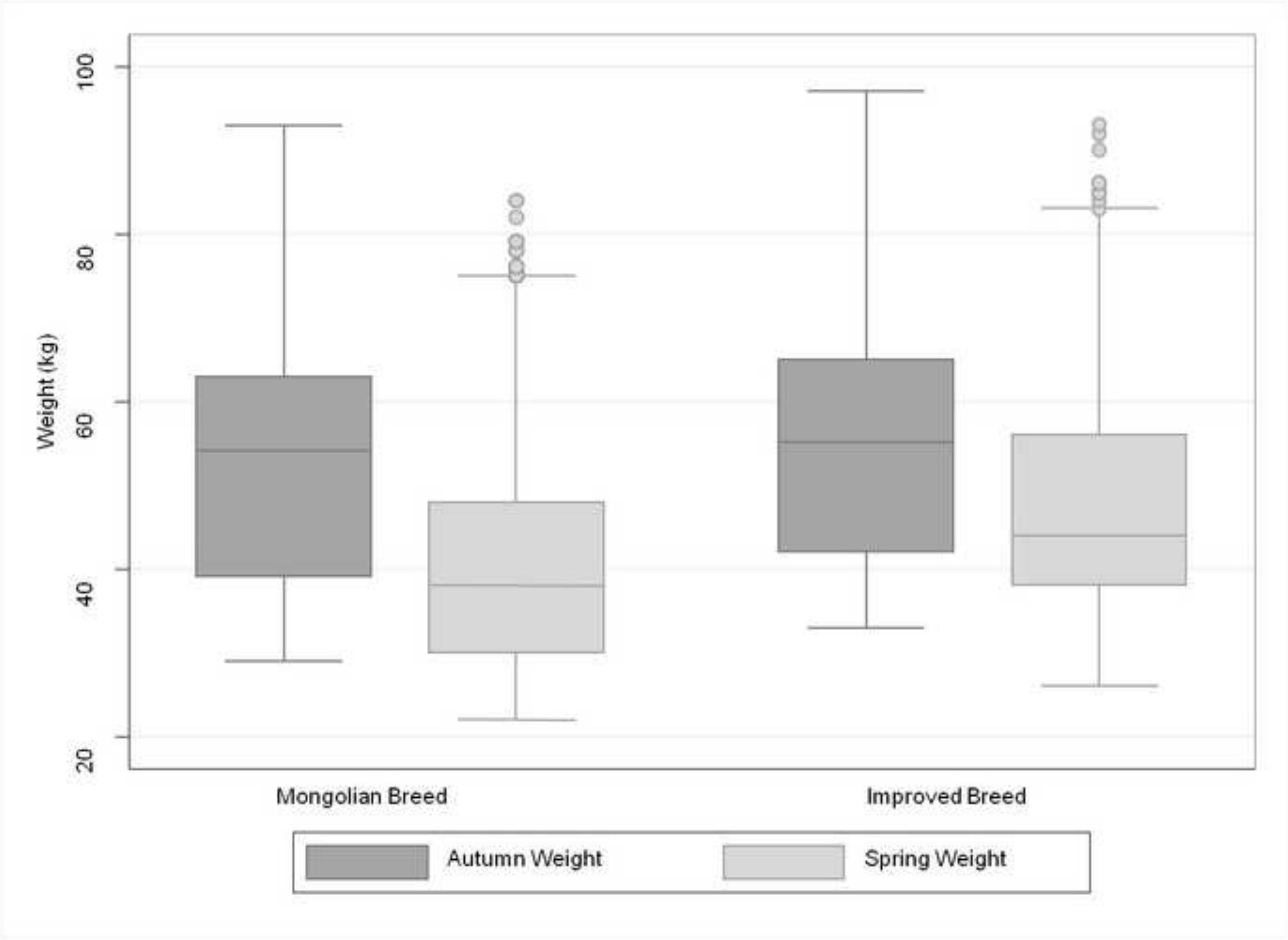
Figures

Figure 1: Boxplot of autumn weights and spring weights by breed (kg)

Figure 1



Weight (kg)
100
80
60
40
20
Mongolian Breed
Improved Breed
Autumn Weight
Spring Weight

Conflicts of interest

The authors declare no conflicts of interest that have affected the conduct of the research reported in this paper.