Peer-reviewed paper: Proc. 43rd Congress of the South African Society for Animal Science

Invited paper

Environmental-genotype responses in livestock to global warming: A southern African perspective

M.M. Scholtz[1,2#], D. Furstenburg[1], A. Maiwashe[1], M.L. Makgahlela[1], H.E. Theron[1] and J. van der Westhuizen[1]

[1] ARC-Animal Production Institute, Private Bag X2, Irene 0062, South Africa

[2] Post graduate School in Animal Breeding, University of the Free State, P.O. Box 339, Bloemfontein 9301, South Africa

Abstract

Global warming will change Southern Africa's environments from grass dominated vegetation to dry woodland and desert with a vegetation of C_4 dominated grasses, whereas the grazing capacity is expected to decline by more than 30%. Animals will also be more exposed to parasites and diseases, mainly as a result of an increase in temperature. An improved understanding of the adaptation of livestock to their production environments is thus important, but the measurement of adaptation is complex and difficult. Proxy-indicators for adaptation, such as reproductive and production traits, can however be used. Adaptation can also be characterized indirectly by describing the production environment in which a breed or population has been kept over a period of time and to which it has become adapted. By describing production environments it will be possible to identify breeds or genotypes that may be adapted to the changed environment of an area. In respect of quantitative breeding technology, fixed and random effects that account for spatial and temporal variation in production environments will have to be identified and physiological breeding value estimations may be necessary. Tools will need to be developed to overlay geo-referenced data sets available onto the different production environments in order to quantify them. Gene or marker assisted selection may play an important role in selection for disease and parasite resistance or tolerance, since it is difficult to measure these traits directly. The development of a high-throughput SNP or gene chip (genomic selection based on Single Nucleotide Polymorphisms) may enhance the utilization of marker assisted selection. Recent research has indicated that the inclusion of information from DNA analysis into BLUP breeding values may result in substantial increases in genetic gain at reduced cost. Strategies that utilizes EBVs derived from genomic analyses (genomic EBVs), together with conventional mixed model methodology, may speed up the process of breeding animals that are adapted to the newly created environment as a result of global warming.

Keywords: Global warming, livestock production, adaptation, animal breeding
Corresponding author. E-mail:GScholtz@arc.agric.za

Introduction

Tropical and subtropical climates have both direct and indirect effects on livestock. Factors such as temperature, solar radiation, humidity and wind all have direct effects on animals, whereas factors such as digestibility of feed, intake, quality and quantity of grazing, pests and diseases all have indirect effects on animals. Ambient temperature is the major factor that has the largest direct effect on livestock, whereas nutritional stress has the largest indirect effect on the grazing animal (Linington, 1990).

Reports indicate that global warming could become a reality as soon as 2009, and the predictions are that the temperature of half of the years between 2009 and 2014 will be warmer than that of 1998, which was the warmest year on record. It is predicted that climate change will have a more extreme effect on the African continent than on any other continent and the prediction is that temperatures will rise by a minimum of 2.5 °C by 2030 (Ashdown, 2007).

The anticipated global warming will change Southern Africa's environments from grass dominated vegetation to dry woodland and desert with a vegetation of C_4 dominated grasses (Wilson & Minson, 1980), and the grazing capacity is expected to decline by more than 30% (Furstenburg & Scholtz, 2009). Animals will also be exposed to different parasites and diseases (ICCP, 2007) as indicated from the predicted change in the distribution of, for example, tsetse fly in Africa (Herrero *et al.*, 2008); putting an even greater pressure on production and the survival of livestock breeds.

Peer-reviewed paper: Proc. 43rd Congress of the South African Society for Animal Science

Adaptation in livestock encompasses the interaction between the total environment and the genetic make-up of an animal. A clear concept is therefore required of how the different environmental factors influence the animal and methods to identify and breed adapted animals.

Discussion

Ambient temperature is the factor that has the largest direct effect on livestock production. Most livestock perform at their best at temperatures between 4 and 24 °C (McDowell, 1972). In the tropics and subtropics temperatures frequently rise above this comfort zone and it is therefore important that livestock are adapted to these higher temperatures (Linington, 1990). High temperatures and solar radiation decreases intake in order to reduce digestive heat production, and reduce grazing time (animals do not graze in hot midday hours), whereas sweating and water intake increases. Other factors involved in thermal comfort include the external coat of the animal (thickness, structure, thermo isolation, absorption and reflectivity) and body traits (shape, size and superficial area) (Bonsma, 1983; Silva, 2000).

Nutritional stress has the largest indirect effect on the grazing animal in the tropics and subtropics. In these environments, natural pasture has both lower nutritional value and lower tiller density than in temperate regions (Linington, 1990). These tropical grasses (C_4) have developed a different photosynthetic pathway to adapt to the climate. The C_4 refers to a 4 carbon compound compared to a 3 carbon compound (C_3) in temperate grasses. C_4 plants have a higher photosynthetic rate, which results in high fibre content, low stem to leaf ratio, reduced digestibility and intake (Leng, 1984). Climate change will thus have the greatest impact on ruminant species (Blackburn & Mezzadra, 2006).

As a result of global warming, livestock in Southern Africa will need to adapt to higher ambient temperatures, lower nutritional value of the grass, and expansion of especially ticks and tick borne diseases. Under such challenges balancing genotypes with production environments will become a crucial element requiring the utilization of diverse genetic resources with appropriate genetic potentials for growth, milk production, resistance to disease and prolificacy (Blackburn & Mezzadra, 2006). The question is how to measure adaptation and how to select for it.

Kolmodin *et al*. (2002), Misztal & Ravagnolo (2002) and Neser *et al.* (2008) emphasize the reality of genotype X environment (GxE) interaction and the need to have genotypes that match the production environment. Reports have also showed that selection for adaptability is possible; however, indigenous or composite genotypes may already have a comparative advantage in the context of climate change.

Measurement of Adaptation

An improved understanding of the adaptation of livestock to their production environments is important, but adaptation is complex and thus difficult to measure. Extensive research has been conducted on the direct measurement of adaptation. This included direct measurements on the animal such as rectal body temperature, respiration rate, pulse rate, water loss, skin thickness and hair per cm^2. In addition, more sophisticated measurements investigated, included the heat tolerance test where the difference in body temperature was measured before and after exposure to extreme heat, and temperature change associated with exercising the animals (Bonsma, 1980; 1983).

Several proxy-indicators for adaptation are available and have also been used (McManus *et al*., 2008). These include reproductive traits such as fertility, survival, birth rate and peri-natal mortality; production traits such as growth rate, milk production, low mortality and longevity; and health traits such as faecal egg counts and number of external parasites (Bonsma, 1980; 1983; Spickett *et al.*, 1989*;* Scholtz *et al.*, 1991; McManus *et al.*, 2008).

Adaptation can also relate to either resistance or tolerance. Resistance means that animals do not get affected by unfavourable conditions, or they quickly get accustomed to them. Tolerance means that the animals stay affected but continue to live, with or without some degree of discomfort (Raberg *et al.*, 2007; McManus *et al.*, 2008).

Examples of adaptation

Weight loss in the Afrikaner after 24 hours without water was only 2% whereas it was 15% in an exotic breed (Hereford). A 24 hour period of water deprivation also did not reduce the feed intake of the Afrikaner, whereas that of the exotic breed was reduced by 24% (Bonsma, 1980).

Peer-reviewed paper: Proc. 43rd Congress of the South African Society for Animal Science

A nitrogen (N) deficient diet reduces feed intake by limiting microbial growth and organic matter digestion in the rumen. This reduces the amount of amino acids available for digestion and absorption from the small intestines. The optimum level of ammonia (NH_3) in the rumen of cattle for proper microbial activity is 50 mg/L (Roffler & Satter, 1975). It was observed that Nguni cattle were more capable of maintaining their body weight during winter than other breeds and they had higher blood urea (N) and ruminal NH_3 levels. It is interesting to note that the Nguni maintained a NH_3 level of 45 mg/L during winter, which is slightly below the optimum level of 50 mg/L (Linington, 1990; Scholtz & Linington, 2006).

It has been demonstrated that the Nguni breed is the most resistant to ticks of all breeds in South Africa and that its production is least effected by ecto parasites (Spickett *et al*., 1989; Scholtz *et al*., 1991). In the case of the Nguni, tick infestation resulted in a weaning weight reduction of only 4.4 kg, whereas it was 29.5 kg in the case of the exotic breed (Hereford) under situations of severe tick infestation.

The grazing and movement behaviour of animals can also be associated with adaptation. In winter the Nguni animals alter their behaviour to improve their energy economy. During this time of poor nutrition and weight loss they spend less time grazing; grazed while walking; rested longer and walked slower. The Ngunis also do not just sniff as the other animals are urinating, but they physically drink the urine. This would result in higher plasma urea levels which in turn may have a beneficial effect on intake and fermentation (Osler, 1996).

Description of production environments

Adaptation can also be characterized indirectly by describing the production environment in which a breed or population has been kept over a period of time and to which it has become adapted. By describing production environments it will be possible to identify breeds or genotypes that may be adapted to the changed environment of an area (FAO/WAAP, 2008). It will thus be necessary to link performance with the production environment. Such information can then be included in genetic evaluations either as part of the predictive model or as a “post breeding value prediction” calculation. This will require further research to identify and prioritize variables that can describe the genetics, management and climate of each herd more accurately.

Good quality environmental data describing production environments already exists (FAO/WAAP, 2008). Variables on temperature, relative humidity, precipitation (including variation in rainfall), day length and radiation are available through Geo-referenced Information Systems (GIS) layers. It is therefore important that GPS waypoints are recorded with the animal performance information.

Quantitative breeding technology

Statistical science continues supporting animal breeding and genetics, and very sophisticated, high-dimensional, models have been applied in this field (Gianola, 2006). The challenge now is to identify fixed and random effects, in respect of quantitative breeding technology, that account for spatial and temporal variation in production environments for use in genetic evaluations.

Further research is needed to identify and prioritize variables that can describe the genetics and management levels of each herd more accurately (Neser *et al*., 2008). The estimation of separate breeding values (EBV’s) for different production environments may even be necessary in extreme cases. The potential use of physiological breeding values (PhBV) to deal with the new dimensions brought about by climate change should also be considered. The difference between PhBV and conventional breeding value (BV) is the way in which genetic potential is defined (Bourdon & Enns, 1998). Per definition these breeding value predictions can also be classified as specific versus general breeding values.

Unlike conventional breeding value predictions, PhBVs are not population dependent. Conventional breeding values depend on the genetic merit of the population in which it was evaluated, but the PhBV does not. In Neser *et al.* (2008), Bonsmara bull 4492 has an EBV of +8.29 for weaning weight in environment 3 and an EBV of +19.20 in environment 4. His PhBV, however, would remain the same – perhaps 245 kg, regardless of the environmental grouping in which he was evaluated.

Physiological breeding values (PhBV) are environment independent, and they do not change under different environmental conditions. They predict performance potential in just one environment – the optimal one. However they are model dependant as is the case with all breeding values. Furthermore, PhBVs alone do not indicate the phenotype, but when combined with information about the physical environment and management, they can be translated into performance measures through simulation models.

As mentioned earlier, proxy-indicators are available to use in selection for adaptation. Unfortunately it is only in the case of growth traits that quantitative breeding technology has succeeded in the prediction of breeding values that are not problematic. Traits linked to fertility and/or survival (days to calving, calving interval, stayability, calving tempo) are all influenced significantly by management or arbitrary decisions taken by breeders or scientists. The appropriate quantitative breeding technology to properly handle these traits still needs to be developed.

With respect to parasite resistance adequate quantitative breeding technology exists and heritability for such resistance seems to be high (Scholtz *et al*., 1989; Cloete *et al*., 2000). The challenge is to collect sufficient information that can be used for selection. Tick counts seem to be straight forward and albeit cumbersome, it is not difficult to perform. The estimation of internal parasite infestation is more challenging and includes aspects such as faecal egg counts, famacha scores and super flotation.

Marker assisted selection

With respect to gene or marker assisted selection (DNA testing) breeders have been promised for years that it will change the way they breed livestock. However, currently only a few of such tests are available for production traits.

Recent research has indicated that the inclusion of information from DNA analysis in the genetic evaluations or estimation of breeding values may result in substantial increases in genetic gain at reduced cost (Meuwissen *et al*., 2001; VanRaden 2008; VanRaden *et al*., 2009). Strategies that utilizes EBVs derived from DNA information (genomic EBVs), together with conventional mixed model methodology, may speed up the process of breeding animals that are adapted to the newly created environment as a result of climate change.

The developments in Quantitative Trait Loci (QTL) (Williams, 2005), and high-throughput SNP's or gene chips (genomic selection based on Single Nucleotide Polymorphisms) may enhance the detection and fine mapping of many genes and QTLs, that for example affect tick resistance. It is foreseen that the utilization of marker assisted selection will play a major role in selection for disease and parasite resistance or tolerance.

Marker assisted selection and proteomics may also be valuable in selection for secondary traits linked to adaptation, such as the gene(s) for high levels of blood urea (N) and ruminal NH_3 in certain genotypes, associated with adaptation to low quality C_4 grasses. At molecular level it may also be important to pay attention to heat-shock proteins (Morimoto *et al.*, 1994) and its relationship to adaptation.

Conclusion

Climate change will influence livestock production and therefore an improved understanding of adaptation of livestock to their production environment is important. Descriptions of production environments are therefore vital for the meaningful evaluation of performance data and comparison of performance of different genotypes. Studies and recording programmes that measure performance will require a description of the environment or environments in which the measurements are taken. Tools will therefore need to be developed to overlay geo-referenced data sets available onto the different production environments in order to quantify them.

Breeding objectives that emphasize proxy-indicators of adaptation need to be streamlined or developed, and special emphases should be put on those associated with fertility. It is thus disappointing that a breed society in South Africa has lowered the breed's fertility standards because the breed "is not adapted to some of the current production environments". Fortunately there are also breed societies in South Africa who are increasing the fertility standards to ensure continued adaptation, as measured by fertility, to the production environment.

The development of a high-throughput SNP or gene chip may enhance the implementation of marker assisted and genomic selection. A 50 k SNP chip is currently on the market for bovines and can make a major contribution towards selection for adaptability. An important prerequisite is the establishment of resource (reference) populations (Meuwissen *et al*., 2001; VanRaden, 2008; VanRaden *et al*., 2009) for different environments, which may be costly.

The planning of genetic improvement programmes at a country level will benefit from the availability of information that allows the identification of genotypes that best match the various production systems within the country.

Peer-reviewed paper: Proc. 43rd Congress of the South African Society for Animal Science

References

Ashdown, L., 2007. Effects of global warming on agriculture. S. A. Stud Breeder 18, 28-33.

Blackburn, H. & Mezzadra, C., 2006. Policies for the management of animal genetic resources. Proc. 8th Wrld. Cong. Genet. Appl. Livest. Prod.

Bonsma, J.C., 1980. Livestock Production: A Global Approach. Tafelberg Publishers, Cape Town, South Africa.

Bonsma, J.C., 1983. Man Must Measure: Livestock Production. Agi Books, Cody, W.Y., USA.

Bourdon, R.M. & Enns, R.M., 1998. Physiological breeding values: Rethinking the way we express genetic values for improving production systems. Proc. 6th Wrld. Cong. Genet. Appl. Livest. Prod. 27, 227-234.

Cloete, S.W.P., Dreyer, F.H. & Du Toit, E., 2000. Faecal nematode egg counts in Merino sheep following natural challenge. S. Afr. J. Anim. Sci., 30 (Supplement 1), 24-25.

FAO/WAAP, 2008. Report of the FAO/WAAP Workshop on Production Environment Descriptors for Animal Genetic Resources. Caprarola, Italy, 6–8 May 2008. Eds Pilling, D., Rischowski, B. & Scherf, B.D.

Furstenburg, D. & Scholtz, M.M., 2009. Global climate change and animal production in southern Africa: A short review. Submitted: Livestock Science. (Supplement – 10th Wrld. Cong. Anim. Prod.)

Gianola, D., 2006. Statistics in animal breeding: Angels and demons. Proc. 8th Wrld. Cong. Genet. Applied Livestock Production.

Herrero, M., Hanotte, O., Notenbaert, A. & Thornton, P.K., 2008. Potential of modelling animal genetic resources data in relation to other existing data sets. In: Report on the FAO/WAAP workshop on production environment descriptors for animal genetic resources report. Eds Pilling, D., Rischkowsky, B. & Scherf, B., Caprarola, Italy, 6–8 May, 2008, Annexure 2.9.

IPCC, 2007. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change [Core writing team, Eds Pachauri, R.K. & Reisinger, A.]. IPCC, Geneva, Switzerland, 104 p.

Kolmodin, R., Strandberg, E., Jorjani, H. & Danell, B., 2002. 7th Wrld. Cong. Genet. Applied Livestock Production 32, 333-336.

Leng, R.A., 1984. Supplementation of tropical and subtropical pastures for ruminant production. In: Herbivore Nutrition in the Tropics and Subtropics. Eds Gilchrist, F.M.C. & Mackie, R.I., The Science Press, Box 41021, Craighall, 2024, RSA. pp. 129-144.

Linington, M.J., 1990. The use of Sanga cattle in beef production. In: Technical communication No 223, Department of Agriculture. pp. 31-37.

McDowell, R.E., 1972. Improvement of Livestock Production in Warm Climates. W.H. Freeman & Co, San Francisco, USA.

McManus, C., Louvandini, H. & Paiva, S., 2008. Examples of different aspects of adaptive fitness, how they can be measured and possible proxi-indicators. In: Report on the FAO/WAAP workshop on production environment descriptors for animal genetic resources report. Eds Pilling, D., Rischkowsky, B. & Scherf, B., Caprarola, Italy, 6–8 May, 2008.

Meuwissen, T.H., Hayes, B.J. & Goddard., M.E., 2001. Prediction of total genetic value using genome-wide dense marker maps. Genetics 157, 1819-1829.

Misztal, I. & Ravagnolo, O., 2002. Studies on genetics of heat tolerance in Holsteins. 7th Wrld. Cong. Genet. Applied Livestock Production 32, 345-348.

Morimoto, R.I., Tissieres, A. & Georgopoulos, C., 1994. The biology of heat shock proteins and molecular chaperones. Cold Spring Harbor Press, Plainview, N.Y., USA.

Neser, F.W.C., Erasmus, G.J. & Scholtz, M.M., 2008. The use of a cluster analysis in across herd genetic evaluation for beef cattle. S. Afr. J. Anim. Sci. 38, 51-57.

Osler, E.H., 1996. Circadian activity patterns of Afrikaner, Nguni and Simmentaler cattle under extensive veld conditions in the southern Transvaal, South Africa. M.Sc. thesis, University of the Orange Free State, South Africa

Raberg, I., Sim, D. & Read, A.F., 2007. Disentangling genetic variation for resistance and tolerance to infectious diseases in animals. Science 318, 812-814.

Roffler, R.E. & Satter, L.D., 1975. Relationship between ruminal ammonia and non-protein nitrogen utilization by ruminants. J. Dairy Sci. 58, 1880-1889.

Scholtz, M.M. & Linington, M.J., 2006. Is the Nguni adapted to low quality pastures? Nguni Journal, 39.

Scholtz, M.M., Lombard, P.E., De Bruin, D.S. & Enslin, C.B., 1989. Eenvoudige metode vir die beraming van bosluisbestandheid by beeste. S. Afr. Tydskrif. Veek. 19, 121-123.

Scholtz, M.M., Spickett, A.M., Lombard, P.E. & Enslin, C.B., 1991. The effect of tick infestation on the productivity of cows of three breeds of cattle. Onderstepoort J. Vet. Res. 58, 71-74.

Silva, R.G., 2000. Introducao a bioclimatalogia animal. Sao Paulo, Brazil, Ed. Nobel.

Spickett, A.M., De Klerk, D., Enslin, C.B. & Scholtz, M.M., 1989. Resistance of Nguni, Bonsmara and Hereford cattle to ticks in a bushveld region of South Africa. Onderstepoort J. Vet. Res. 56, 245-251.

VanRaden, P. M., 2008. Efficient methods to compute genomic predictions. J. Dairy Sci. 91, 4414-4423.

VanRaden, P.M., Van Tassell, C.P., Wiggans, G.R., Sonstegard, T.S., Schnabel, R.D., Taylor, J.F. & Schenkel, F.S., 2009. Invited review: Reliability of genomic predictions for North American Holstein bulls. J. Dairy Sci. 92, 16-24.

Williams, J.L., 2005. The use of molecular marker-assisted selection in animal breeding and biotechnology. Rev. Sci. Tech. Off. Int. Epiz. 24, 379-391.

Wilson, J.R. & Minson, D.J., 1980. Prospects for improving the digestibility and intake of tropical grasses. Trop. Grassl. 14, 253.