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The farm-gate methane intensity and blue water footprint of nine diverse beef cattle breeds in South Africa

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Abstract

A simulation study was done to estimate the methane intensity and blue water footprint of a weaner calf production system in South Africa. Nine genotypes, representative of indigenous, British, Zebu, and European breeds, were chosen based on their relative numbers and the availability of data. A farm of 1200 ha with a carrying capacity of 6 ha/large stock unit (LSU), which could thus carry 200 LSU in total, was simulated. The enteric methane emission of an LSU was estimated to be 94 kg of methane/year (tier 2), implying that 18 800 kg of methane was produced per year by the farm (200 LSU × 94 kg of methane). Likewise, the litres of blue water consumed on the farm was 3285 kilolitres (200 LSU × 16 425 litres/year/LSU). The methane intensity (kg methane/kg live weight) was calculated by dividing the annual methane emissions of the farm by the total kilograms of live weight leaving the farm. The blue water footprint was estimated similarly. The total live weight leaving the farm was calculated by combining the total kilograms of saleable calves and the total kilograms of culled cows sold. The Afrikaner, Bonsmara, Angus, Brahman, and Brangus breeds had low methane intensities and blue water footprints, while the European breeds had high values. The methane intensity varied from 0.59 kg of methane to 0.85 kg of methane, a 44% difference. The water footprint varied from approximately 100 to 150 L/kg live weight leaving the farm. More research is needed to validate these differences.

Keywords: farm size, large stock unit, live weight, simulation study, tier 2 emissions

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Introduction

Beef cattle are frequently accused of producing large quantities of greenhouse gases (GHG) (Steinfeld *et al*., 2006) and using large quantities of water in the production of beef (Meissner *et al*., 2012). However, beef products are an important global source of protein, and some of the assumptions used to calculate the carbon or water footprints of beef products are questionable. In addition, ruminant livestock are important to mankind since most of the world's vegetation biomass is rich in fibre (Scholtz *et al*., 2023). Only ruminants can convert this high fibre-containing vegetation into high-quality protein

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sources (i.e. meat) for human consumption, and this will need to be weighed up against the carbon and water footprints of their products.

Despite the important role ruminant livestock play in human nutrition, they are specifically targeted as producing large quantities of GHGs that contribute to climate change. This is mainly the result of the publication 'Livestock's Long Shadow' by the Food and Agriculture Organization (FAO), which reported that livestock were responsible for 18% of the total GHG emissions (Steinfeld *et al*., 2006). Although this value was later reduced to 14.5% (Gerber *et al*., 2013), it is still an overestimate. More recent estimates (RSA, 2020; Scholtz *et al*., 2020) indicate that the contribution of ruminants to GHGs varies between 4% and 5.5%, with beef cattle contributing the largest proportion. The United States Environmental Protection Agency (EPA) estimates the contribution from beef to be 3.9% in the USA (EPA, 2018).

Scollan *et al*. (2010) cited a study claiming a water requirement of 15 500 L/kg of beef and assumed that it would take three years to produce 200 kg of boneless beef. However, this estimate included rainfall on the property, and only accounted for 155 L of water for drinking, cleaning, and post farm-gate activities, with the remainder used to produce feed for the livestock (water for crop production). In studies with more realistic and justifiable assumptions, the water requirements for red meat production are much lower (Peters *et al*., 2010).

The argument is sometimes advanced that the water used for livestock production should rather be channelled to crop and vegetable production, which requires less water; however, this is not relevant in areas where crop and vegetable production is not viable. In South Africa, agriculture consumes 74.5% of the rainfall in the country. Of this, 60% is utilised by natural vegetation, 12% by dry land crop production, and 2.5% by irrigation (Bennie & Hensley, 2001). Natural vegetation (rangelands) and dry land crop production use only 'green' water, i.e. rainwater that is stored in the soil after precipitation. It is called green water because only green plants growing in the soil utilise this water. It cannot be used by or for anything else. In extensive grazing systems, the natural vegetation, which is the food source of the livestock, uses only green water. This water cannot be used for crop production, since most of these areas are unsuitable for crop production because of inadequate rainfall and/or poor-quality soil (Chapagain & Hoekstra, 2004). The quantity of green water used to produce livestock products (e.g. meat) in extensive rangeland areas is therefore irrelevant in calculating water consumption for beef production (Scholtz *et al*., 2013; Grobler *et al*., 2023), so only the farm-gate blue water footprint is an important estimate for primary beef production systems in South Africa.

The cow-calf production cycle is responsible for most of the energy consumed in the production of meat, and in beef cattle farming it accounts for approximately 72% of the energy consumed from conception to slaughter (Jenkins & Ferrell, 2002). In the mature beef cow, maintenance requirements represent 70% of her total feed expenses, and the average feed cost per cow accounts for 42% of the total annual production cost (Ferrell & Jenkins, 1982). It is therefore clear that if the carbon and water footprints need to be reduced, the cow-calf production cycle should be the starting point.

The study reported here aimed to estimate the farm-gate methane and blue water footprints of a weaner calf production system using the major beef cattle types available in South Africa, i.e., Sanga (indigenous), Sanga-derived, Zebu, Zebu-derived, British, and European. This information should be valuable to the Department of Forestry, Fisheries and the Environment in its efforts to develop an emissions baseline for the agriculture, forestry, and other land use sectors. This is especially important if a carbon tax is to be introduced.

Materials and methods

The study was carried out according to the rules and regulations of the University of South Africa Animal Ethics Committee, and ethical clearance was acquired from the University of South Africa (22/CAES_AREC/062) before the commencement of the study. It should be noted that the Agricultural Research Council (ARC) – Animal Production, Irene, South Africa ethics committee does not provide ethical clearance for the use of secondary data, as the data used for such studies are available in the public domain.

A simulation study was used to estimate the methane production (expressed as the methane intensity in kg methane/kg live weight) and blue water footprint of a weaner calf production system for diverse beef cattle genotypes. Nine beef cattle genotypes were chosen, based on the number of animals and the availability of data. The genotypes included were the Afrikaner and Nguni (Sanga), Bonsmara

(Sanga-derived), Angus and Hereford (British), Brahman (Zebu), Brangus (Zebu-derived), and Charolais and Simmentaler (European).

Neser (2012) developed a generalised simulation programme to estimate the outputs of beef cattle from different systems and using different breed types. The ARC subsequently developed regression equations for different frame sizes (i.e. small-, medium-, and large-frame), and physiological stages (i.e. lactating cow, replacement heifer, weaner calf, and breeding bull, etc.). These equations can be used to calculate individual and total herd LSUs for specific herd compositions (Mokolobate *et al*., 2015). Meissner *et al*. (1983) described an LSU in South Africa as the equivalent of an ox with a live weight of 450 kg, which gains 500 g per day on grass pasture that has a mean digestible energy content of 55%, and which requires 75 MJ per day of metabolisable energy, or approximately 9 kg of dry matter (DM) intake per day. The simulation programme was adapted to include different frame sizes, after which the simulation study was conducted to estimate the carbon and water footprints of farm-gate (primary) beef production.

A farm with an area of 1200 ha and a carrying capacity of 6 ha/LSU, which could thus carry 200 LSU, was simulated. Frame size-specific equations were used to estimate the cow LSU (Mokolobate *et al.,* 2015). Published data obtained from the South African Integrated Registration and Genetic Information System, which stores all data from the National Beef Recording and Improvement Scheme, as summarised by Scholtz (2010), were used (Table 1). Data from this scheme are collected according to approved standard operating procedures and are accredited by the International Committee for Animal Recording. Actual published production values (weaning weight, cow weight, and fertility) for each breed were used (Table 2). Furthermore, a 15% replacement rate, 2% pre-weaning mortality rate, 2% post-weaning mortality rate, and 4% use of breeding bulls was assumed.

Data from 1 289 227 animals over a 10-year period for cow weight (n = 397 848), weaning weight (n = 493 531), and inter-calving period (n = 397 848) were included.

Table 1 Genotypes included in the study and the number (n) of records for the 10-year period on which the national averages were based

Genotypes	Cow weight (n)	Weaning weight (n)	Inter-calving period (n)
Afrikaner	22 662	19 446	22 662
Nguni	51 785	15 282	51 785
Bonsmara	226 445	266 880	226 445
Brahman	3640	3970	3640
Angus	31 731	28 673	31 731
Brangus	Not available	73 148	Not available
Hereford	14 964	13 660	14 964
Charolais	13 220	14 189	13 220
Simmentaler	33 401	58 283	33 401
Total	397 848	493 531	397 848

Calving percentage (%) was calculated according to Roux & Scholtz (1984), using the following equation:

$$Calving\ percentage = 100 - \frac{Average\ intercalving\ period\ per\ year\ -\ 365\ days}{365\ days} \times 100$$

The Afrikaner and Nguni represented the small-frame breeds, the Bonsmara, Angus, Hereford, Brahman, and Brangus represented the medium-frame breeds, and the Charolais and Simmentaler represented the large-frame breeds. The specific herd statistics for the different breeds were estimated using the simulation programme, and the number of animals per category and the respective weights for the simulated 1200 ha farm are presented in Table 3. This information was used to estimate the methane intensity and blue water footprint.

Table 2 Breed statistics used to estimate the methane intensity and blue water footprints of a simulated 1200 ha farm with a carrying capacity of 200 large stock units

Genotype	Cow weight (kg)	205-day calf weight (kg)	Inter-calving period (days)	Calving percentage (%)	Weaning percentage (%)
Afrikaner	467	191	448	77	75
Nguni	367	155	404	89	87
Bonsmara	503	217	414	87	84
Angus	515	219	419	85	82
Hereford	540	204	398	91	88
Brahman	520	214	455	73	71
Brangus	488	203	450	77	75
Charolais	630	232	430	82	80
Simmentaler	553	241	474	70	68

Table 3 Herd statistics used to estimate the carbon and water footprints of a simulated 1200 ha farm with a carrying capacity of 200 large stock units

Genotype	Number of cows with calves	Number of saleable calves	Calf weight (kg)	Total kg of weaner calf	Number of culled cows	Cow weight (kg)	Total kg of culled cows	Total kg live weight leaving farm
Afrikaner	135	115	191	21 965	20	467	9340	31 305
Nguni	147	125	155	19 375	22	367	8074	27 499
Bonsmara	123	105	217	22 785	18	503	9054	31 839
Angus	120	102	219	22 338	18	515	9270	31 608
Hereford	115	98	204	19 992	17	540	9180	29 172
Brahman	119	101	214	21 614	18	520	9360	30 974
Brangus	126	107	203	21 721	18	488	8784	30 505
Charolais	77	66	232	15 312	11	630	6930	22 242
Simmentaler	90	77	241	18 557	13	553	7189	25 746

The tier 2 approach of the Intergovernmental Panel on Climate Change (IPCC) for methane emission values was used (IPCC, 2006). Through this approach, it was estimated that the enteric methane emissions factor of an LSU is 94 kg methane/year (Du Toit *et al*., 2013). The methane intensity was calculated by dividing the annual methane emissions from the farm per year (200 LSU × 94 kg methane = 18 800 kg methane) by the total kilograms of live weight leaving the farm annually. The total live weight available for disposal annually was calculated by adding the total kilograms of saleable calves to the total kilograms of culled cows.

The blue water footprint of beef production was also estimated using an LSU as the reference. A general guideline for water intake is that for every kilogram of DM intake, a ruminant animal needs to consume 4 L of water, but this can increase by 50% under hot conditions (Wagner & Eagle, 2021). Therefore, an average of 5 L of water was used. It was therefore estimated that in South Africa the average water intake of an LSU is 45 L/day (9 kg DM intake × 5 L) or 16 425 L/year. The 200 LSU on the simulated farm are thus estimated to drink 3285 kL/year. The blue water footprint was estimated by dividing the 3285 kL of water by the total kilograms of live weight leaving the farm annually.

Results and discussion

The estimated methane intensity of the nine diverse beef cattle genotypes is presented in Table 4. In the case of the Afrikaner, for example, the total kilograms of weaner calves available for sale was calculated as: 115 calves × 191 kg weaning weight = 21 965 kg of weaner calves (Table 3). Likewise, the total kilograms of culled cows was calculated to be 9340 kg (20 cows × 467 kg). The total kilograms of live weight leaving the farm was thus 31 305 kg (21 965 kg + 9340 kg). In the case of the Afrikaner, the methane intensity (kg methane/kg live weight leaving the farm) was calculated as 18 800 kg methane/31 305 kg live weight, producing a value of 0.60 (Table 4).

Table 4 The methane intensity and carbon dioxide equivalents of nine diverse beef cattle genotypes on a simulated farm in South Africa

Genotype	Methane intensity (kg methane/kg live weight)	Carbon dioxide equivalents
Afrikaner	0.60	13.8
Nguni	0.68	15.6
Bonsmara	0.59	13.6
Angus	0.59	13.6
Hereford	0.64	14.7
Brahman	0.61	14.0
Brangus	0.62	14.3
Charolais	0.85	19.6
Simmentaler	0.73	16.8

In order to compare the results from this study with results reported in the literature, the carbon dioxide equivalent (CO_2e) was calculated. Information on the major GHGs related to livestock production and their characteristics was adapted by Scholtz *et al.* (2020) from various sources. In this article, the global warming potential of methane is assumed to be 23 times that of carbon dioxide, and this value was used to estimate the CO_2e values presented in Table 4 (Brander, 2012). From Table 4, it can be seen that the methane intensity varied from 0.59 kg for the Bonsmara and Angus breeds, which had the lowest methane intensities, to 0.85 kg for the Charolais breed, which had the highest methane intensity. This is a difference of 44%, and indicates that small- to medium-frame breeds may be more efficient in terms of methane production than large-frame breeds in a weaner calf production system in South Africa.

The low methane intensities of the Afrikaner, Bonsmara, Angus, Brahman, and Brangus breeds suggest they can be regarded as environmentally friendly. The Nguni and Hereford breeds have medium or fair methane intensities, while the Charolais and Simmentaler have high methane intensities, and may be regarded as environmentally unfriendly. Remarkably, the Nguni had a fairly high methane intensity, despite being the most fertile of all the breeds. However, it should be taken into account that since the Nguni was the smallest breed, a total of 147 cows with calves could be kept on the 1200 ha farm, and these cows and calves produce large quantities of methane. In addition, the weaning weights of Nguni calves are very low, and the bottom line is that fewer kilograms of meat are produced by the farm when using this breed. Although the data used in the study were derived from extensive production systems, there may still be differences between the different breeds in the lick or supplementary feed provided. Performance variation between herds may also be greater in some breeds than in others. These factors should be considered when interpreting the results.

Research conducted in Europe estimated the carbon footprint of beef production to be 11.6 kg CO_2e/kg live weight for weaner production systems in Ireland, and 8.6 to 15.6 kg CO_2e/kg live weight for dairy and weaner production systems throughout Europe (Cederberg & Stadig, 2003). In Australia, Ridoutt *et al*. (2011) evaluated six beef cattle production systems where animals were grazed on improved pastures and finished in a feedlot, and the estimated values of their carbon footprints ranged from 10.1 to 12.7 kg CO_2e/kg live weight. The results of this study range from 13.6 to 18.2 kg CO_2e/kg live weight, while the values from the literature that can be compared with this study range from 8.6 to 15.6 kg CO_2e/kg live weight. This suggests that this study's findings are consistent with those found in the literature. It should be noted that no previous comparable research has been done in South Africa.

The estimated blue water footprints of the diverse beef cattle genotypes are presented in Table 5. The results of the simulations showed that the blue water footprint per kilogram live weight leaving the farm differed greatly between the breeds, varying from 103 to 148 L/kg live weight leaving the farm. The water-use intensities of the small- and medium-frame breeds, such as the Afrikaner, Bonsmara, and Angus, were low (103 to 105 L/kg), while the large-frame breeds (Charolais and Simmentaler) had high water-use intensities (128 to 148 L/kg). When other breeds were compared to the Afrikaner, Bonsmara, and Angus, the blue water footprints of the Hereford, Brahman, and Brangus were 10% higher, while those of the Nguni, Simmentaler, and Charolais were 20%, 30%, and 50% higher, respectively. However, management methods may differ between these breeds, and this may have an influence on the results.

Table 5 The blue water footprints of nine diverse beef cattle genotypes on a simulated farm in South Africa

Genotype	Blue water footprint (L water/kg live weight)
Afrikaner	105
Nguni	120
Bonsmara	103
Angus	104
Hereford	113
Brahman	106
Brangus	108
Charolais	148
Simmentaler	128

The water footprint values found in the current study seem to be very low, in comparison to the results reported by Mekonnen & Hoekstra (2012), who found the water footprint for a kilogram of boneless beef to be between 15 415 L/kg and 17 387 L/kg in their global assessment of the water footprints of farmed animal products. However, when Junior & Dziedzic (2021) estimated the blue water footprint for cows, the water consumed was 154 L/kg live weight leaving the farm, while for bulls it was 95.63 L/kg live weight leaving the farm. These figures are more consistent with the current study's calculations, which showed that the blue water footprint ranged from 103 to 148 L/kg live weight leaving the farm. There is a paucity of research on the water footprint of beef cattle production, both globally and in South Africa. Even though South Africa is well known for producing large amounts of beef, insufficient research has been done on the assessment of the water footprint in extensive systems.

Conclusions

The findings of this study provide valuable insights for the estimation of the farm-gate methane intensity and blue water footprint. Updated information on the performance of beef cattle under different production systems (communal, emerging, and commercial) and levels of production, and using different breed types, must be available to develop baseline emissions for the beef cattle sector for the promotion of sustainable production with low environmental impacts. A central database is therefore important. The financial aspects and benefits of farming with different breed types and using structured cross-breeding systems, and the possible resultant differences in carbon sequestration, should also be considered in future studies.

These results highlight the importance of considering methane production in breeding objectives for beef cattle. A carbon footprint selection index that includes the three component traits, namely calf weaning weight, cow weight, and fertility, should thus be developed. Such an index would be valuable for mitigation strategies, especially since the implementation of carbon taxation measures is possible in the future. The same approach can be used to estimate changes in the farm-gate blue water footprint of beef production.

In South Africa, beef is produced from feedlots, as well as from commercial grass-fed farms and communal (small-holder) production systems. The factors that influence the carbon footprints (methane intensities) of these different production systems should be researched and not only quantified but also documented and their trade-offs evaluated. This simulation study supplies interesting information on the farm-gate methane intensity. However, it is important that the methane production of the different breeds is physically measured. It is therefore recommended that the actual on-farm methane emissions of different beef cattle genotypes grazed on sweetveld, sourveld, and bushveld vegetation types over a whole production system, from mating until the weaning of the calf, is measured.

In South Africa (and many other countries), limited information on the total water footprints of different beef production systems is available. This encompasses the blue water (the water consumed by the animals), the 'feedlot feed' water (the water used to produce the feedlot feed), and the grey water (from feedlots and abattoirs). Research that quantifies the different water footprints of the different beef production systems in South Africa is needed.

It is important to note that the data used in this study were derived from extensive production systems, where there may be differences between the different breeds in the lick or supplementary feed provided. Likewise, management methods may differ between the breeds, and this may have had an influence on the results. This must be taken into consideration when interpreting the results of this study.

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Authors' contributions

M.M.S. initiated and conceptualised the study, sourced the funding for the study, and was responsible for writing the first version of this manuscript. N.T.C. did the actual analyses and used the results for her MSc study. M.C.C-M. assisted N.T.C. with the analyses and ensured the simulation programme was used correctly. M.J.M. represented the DALRRD and oversaw the progress of the study and secured the funds. N.O.M. gave guidance in respect of the MSc study. All the authors read and approved this manuscript.

Conflict of interest declaration

The authors declare that they have no conflicts of interest related to the content of this paper.

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