Broom, D.M. 2021. Dairy cattle welfare and other aspects of sustainability. In: Endres, M. ed. *Understanding the Behaviour and Improving the Welfare of Dairy Cattle*, 1-13. Cambridge, UK, Burleigh Dodds Science Publishing.
dx.doi.org/10.19103/AS.2020.0084.01

Pre-publication copy

Ch 1 Dairy cattle welfare and other aspects of sustainability

Donald M. Broom, University of Cambridge, Cambridge, UK (dmb16@cam.ac.uk)

Abstract: Welfare and other aspects of sustainability are becoming increasingly important in consumer purchasing decisions. This chapter introduces a number of key welfare issues affecting the dairy industry that need system change, including lameness, mastitis and aspects of calf management. Other major topics concerning the sustainability of dairy production are: minimising grain use, feeding high protein leaves of shrubs and trees, reducing greenhouse gas emissions such as by changing diet to reduce methane output, and improving labelling and traceability.

Key words: animal welfare, sustainability, greenhouse gas, biodiversity, dairy cows, calves.

Contents:

1 Introduction

Future animal production, indeed all kinds of production, will have to be sustainable. A system or procedure is sustainable if it is acceptable now and if its expected future effects are acceptable, particularly in relation to resource availability, consequences of functioning and morality of action (Broom 2014, modified after Broom 2001, 2010). The development of new, sustainable systems is urgently needed because some current livestock production practices are not acceptable to consumers, many of whom now include the ethics of food production in their evaluation of product quality (Broom 2010). The opinion of the public is based on a range of components of sustainability, including welfare (Table 1).

Table 1 Some factors which might make a food production system unsustainable

Inefficient usage of world food resources
Adverse effects on human welfare, including health
Poor welfare of animals
Harmful environmental effects (a) too much greenhouse gas production
(b) low biodiversity
(c) insufficient conservation
Unacceptable genetic modification

After an era when negative effects on consumer health have been a major factor in attitudes to some foods, poor welfare of animals is now a substantial factor in consumer purchase decisions which affect the sustainability of animal production systems (Bennett et al 2002, Broom 2014, 2017a). Recently, production practices negatively affecting the world’s climate and biodiversity have also become more important. In the long run, inefficient use of world resources is likely to influence the public greatly but any of these factors can result in a product being avoided by consumers. It is therefore very important for producers to consider all aspects of sustainability, including welfare, if they are to hold on to their markets. The dairy industry is particularly vulnerable because some of its production practices have come under sustained criticism in recent years. What can it do to meet changing consumer expectations? Since there are many facets of welfare and other aspects of sustainability, many kinds of measurement are needed (Von Keyserlingk et al 2013).

2 Animal welfare and the dairy industry

Major welfare problems of dairy cows include lameness, mastitis, impaired reproduction, inability to show normal behavioural and physiological responses, infectious diseases and injury (see review by EFSA 2009). Efforts are being made to address these problems but the first three are still worse in high-producing dairy cows (Schukken et al 2005, Oltenacu and Broom 2010,). It would seem that many dairy cows are at or beyond a production level that is metabolically damaging to them (Knaus 2009). The problems are also worse in cows treated with bovine somatotrophin, which can further increase milk yield and metabolic pressure (EU SCAHAW 1999). Dairy cows have been selected for high production to too great an extent so selection factors should be changed to reduce production per cow in order to protect the future of the industry. Also, cows should not be fed an amount or a diet that exacerbates the metabolic disorders leading to lameness, mastitis and reproductive problems. Welfare issues affect both extensive and intensive production systems. None of the problems is necessarily worse in large dairy herds than in small ones but some aspects of welfare, such as outdoor access, may be more challenging to address in large herds (Broom 2013). On the other hand, large herds can have in-house specialized labor (e.g., hoof trimmer and veterinary care) which can improve other aspects of welfare such as animal health (Robbins et al., 2016).

2.1 Lameness

There are many methods for grading lameness and, as a result, estimates of the prevalence of lameness vary widely. Cook et al. (2016) reported a lameness prevalence of 9.6% in high performance dairy herds ranging in size from 203 to 2966 cows while others report prevalences of 39% or higher (Archer et al., 2010; Bell, 2017). Barker et al (2010) concluded that a lameness prevalence of 37% is typical of the industry in much of the world and Bell (2017) suggested lameness may affect a third of adult dairy cattle, with the majority of animals experiencing a lameness event in the course of a year. Lameness can be a significant problem in both intensive and extensive systems (Ranjbar et al., 2016).

Health is an important part of welfare and lameness is a clear example of this. Leg and foot disorders involve painful tissue damage and they are also frustrating because many of them prevent normal control of movement. They often cause animals to walk with a limp, reduce walking to a low level, or avoid walking whenever possible (Broom and Fraser 2015). The ability of lame cattle to carry out various preferred behaviours is generally impaired, and there may be adverse consequences for various other aspects of their normal biological functioning. Lameness reduces ability to obtain some resources, such as food, water and preferred lying places. Lameness always means some degree of poor welfare, and sometimes means that welfare is very poor indeed. EFSA (2009) concluded that no farms should continue to produce milk without urgent remedial action if more than 10% of cows are lame at any time. Lameness affects production as well as welfare: Archer et al (2010) found that lame cows produced about 1 kg less milk per day. There is a wide range of clinical causes of lameness in dairy cows (Bran et al 2019) and the clinical condition can be treated using appropriate analgesia (Stilwell et al 2019).

The clear measurable welfare outcome of lameness is that the cow shows difficulty in walking and consequent alteration of gait. This can be identified by direct observation of the animal while walking or while attempting to move or walk. Those assessing lameness use points on a scale of walking ability to characterise each individual. Cows that are lame walk less often to particular resources and walk less in total. Some automated measurement methods can be used, especially for the total amount of walking by the individual, but direct observation by a skilled observer is still the best measure. A criterion for lameness that is generally usable by inspectors is necessary as farmers often fail to identify lameness, especially milder cases. The extent of lameness in a herd can be assessed by an inspection visit to a farm, or to a slaughterhouse, during which every animal (or a representative sample) is checked.

2.2 Mastitis

Mastitis in mammals is a very painful condition. The teat and udder are very sensitive to touch and there is obvious diminution of normal function. Despite many advances in understanding and treatment, mastitis remains the most economically significant bacterial disease of dairy cattle (Moroni et al., 2017). The incidence of clinical mastitis has been estimated to range from 14 to 40 cases/100 cows per year, and is worst in poorly managed herds and some high yielding herds (EFSA, 2009; Jamali et al., 2018). The prevalence of this serious animal welfare problem might have declined more if there had been less pressure to keep increasing milk yield per cow. The hormone bovine somatotrophin, produced using genetically modified bacteria, increases mastitis and other production-related diseases so its effects are very negative for cow welfare and its use is banned in most countries in the world. Information about mastitis, including sub-clinical mastitis, can be obtained by clinical examination of the cow and by other measures such as white cell count in the milk (Sant' Anna and Paranhos da Costa 2011; Moroni et al., 2018). Herd records should be kept and be made available for evaluation as part of welfare assessment procedures. A threshold for identification of mastitis is required in order that current prevalence during an inspection visit or prevalence as assessed from herd records can be calculated. Every milking cow on a farm or other unit should be taken into account.

2.3 Reproductive disorders

Reproductive disorders are important indicators of poor welfare in dairy cows. Esslemont and Kossaibati (1997) reported that of cows that were culled, 36-44% were culled because of failure to get in calf. This problem has continued to be important, especially in high-yielding cows that are metabolically stressed (Dobson et al 2007, Berglund 2008, Friggens et al 2010, Leroy et al 2015, Diskin et al 2016, Evans and Zeng 2018). Reproductive disorders, lameness and mastitis result in cows being culled earlier in life and hence having shorter lives than they did 20-30 years ago (Compton et al 2017). Cloning of cattle has high risks of poor welfare (Broom 2014, 2018) so many countries do not permit it. The data required for assessing the extent of reproductive disorders on a dairy farm are those from clinical investigation during an inspection visit and those from records of veterinary treatment and from the culling of cows (von Keyserlingk et al 2009).

2.4 Other cow welfare problems

One aspect of more intensive dairy herd management that has attracted concern is housing. Many modern housing systems for cattle involve keeping animals indoors, in a more restricted space, sometimes at high stocking density. This can increase the chance of injury, spread of disease and heat stress as well as cause poor welfare by restricting behaviour (EFSA, 2009; Polsky and von Keyserlingk 2017; Rushen, 2018). Whilst cows prefer an adequate to an inadequate food supply (which can be better controlled in intensive systems), they also show clear preferences for access to pasture rather than continuous housing (Spörndly and Wredle 2004, Legrand et al 2009, Charlton et al 2011, 2013, Von Keyserlingk et al 2017). Husbandry practices that have caused concern include tail-docking (Broom and Fraser 2015), which most dairy cattle welfare programs around the world have banned (e.g., FARM Program in the USA), the need for caesarean section because of breed or impregnation by too large a bull, and embryo loss when cloning is used. Dystocia and other abdominal pain cause poor welfare and the use of analgesia during all parturition can have beneficial effects (Stilwell et al 2014). Hot conditions cause poor welfare in cattle and measures of heat stress in cows are described by Polsky and von Keyserlingk (2017).

2.5 Calf welfare problems

The process of parturition can be a stressful, traumatic and hazardous event for both cow and calf. It has been estimated that up to 10% of heifers, when stillbirths are included, may die before weaning in the United States with lower rates in Europe and elsewhere (Miller-Cushon et al., 2018). In the first few days after birth, the major calf welfare problems are enteric and respiratory diseases, identifiable by clinical signs. The calves of dairy cows may fail to obtain sufficient colostrum for a variety of reasons, and will then be more susceptible to disease, so checks on suckling or measurement of immunoglobulin concentration in the blood give information about welfare. The diet of the calf should have sufficient iron to prevent anaemia and, a little later in life, sufficient fibre to promote normal gut development (Phillips 2002, Broom and Fraser 2015). Both of these effects and immune system function can be used as welfare indicators.

Most dairy calves are separated from their mothers at an early age to be reared individually with potentially negative welfare consequences (Phillips, 2017). Measurable signs of poor welfare in calves reared in individual crates or pens include: stereotypies;

difficulties in standing, lying and grooming; excessive grooming of the front of the body with the ingestion of much hair and the formation of hairballs in the gut; and substantial adverse reactions to walking and to transport (Broom and Leaver 1978, Veissier et al 1994, Broom 1996, Boe and Faerevik 2003, Gaillard et al 2014, Broom and Fraser 2015). In contrast, group housing, if well managed, improves feeding, health, and development of behavior and cognition (Miller-Cushon el al., 2018). Calves may also be subjected to practices that cause pain including castration and horn-disbudding, resulting in measurable pain-related behaviours preventable by anaesthesia and analgesia (Stafford and Mellor 2005, Stilwell et al 2008a, b, 2009, 2010, 2012).

An ethical problem for the dairy industry is the production of unwanted male calves. If these calves are removed from the cow and humanely killed, there is no welfare problem for the calf. However, if they are handled roughly, transported in inadequate ways or kept in conditions that do not provide for their needs, their welfare will be poor. These last points apply also to female calves. The veal industry developed, in part, as a response to the production of unwanted male calves. The solution to this problem may well be the sexing of semen so that no unwanted calves are produced.

3 Dairy production, welfare and sustainability

As has been noted, production methods can have negative welfare impacts which need to be properly understood and addressed. Different methods also have broader environmental impacts which themselves have welfare implications, such as hotter and drier conditions related to climate change which livestock may have to face (Pryce and de Haas, 2018). Consumers concerned about the effects of dairy products on their health can now access good information about how to manage cholesterol levels, avoid obesity and also take advantage of the nutritional benefits of dairy products. With well-controlled labelling and traceability, consumers can choose to buy products that are high welfare, low greenhouse gas emission, fair trade and otherwise sustainable. These issues have major consequences for the future survival and success of dairy farming.

It is well known that herbivorous animals such as cattle and sheep can consume material that humans cannot consume (e.g. grass) and convert it an edible form (e.g. meat or milk). Many parts of the world are not suitable for arable crop production but can support pasture, suggesting that extensive, pasture-based dairy production, if properly managed, can be an efficient and sustainable use of available world resources (Marshall and Collins, 2018).

However, while grasses continue to dominate feed resources for livestock production globally, feed from sources such as grain may represent around 30-40% of the diet of dairy cattle in some regions such as North America characterised by more intensive forms of production (Blümmel et al., 2018). The use of grain and other crops as feed has become controversial because of competition for land and other resources with crop production for food (Herrero et al 2010, Broom 2018b, Balmford et al 2018). Stoll-Kleemann and O'Riordan (2015) estimate that 45% of greenhouse gas production from cattle production comes from feed production and processing, with 39% from cow digestion and 10% from their faeces. Feeding energy-dense, highly fermentable diets to optimize milk production can also have welfare implications. If excess grain is fed, this can lead to digestive disorders such as rumen acidosis which has been

estimated to have a prevalence rate of up to 60%, depending on the stage of lactation (Penner, 2018). More broadly, intensive production systems have been linked to other problems such as high energy and input use, lower levels of biodiversity as well as increased rural poverty and inequality with the consolidation of production into a few, large, resource-intensive farming operations (Scott and Gooch, 2017).

There is now huge debate about how to make dairy farming more sustainable, both in terms of welfare and its broader environmental impact. Housed cattle fed on highly digestible crop-derived feeds have high growth rates and feed use efficiencies. The land required for these intensive systems, taking account of land used for feed production, use a similar amount of land to fertilised pasture systems and substantially less than extensive grazing systems (Broom 2019, Woolf, 2020). High dairy production per unit of land makes more land available for other uses such as nature reserves (Balmford et al 2018). Some research is concentrating on how to optimise the environmental benefits of this efficiency whilst reducing negative environmental impacts and dealing with welfare issues linked to more intensive production.

Other research has focussed on how to optimise extensive systems to increase grazing efficiency and optimise product quality while reducing greenhouse gases such as methane, protecting biodiversity and maintaining good animal welfare, including animal health (Woodfield and Judson, 2018). Studies show how to change ruminant diets so as to reduce the rumen population of the microorganisms that produce methane. There is also increasing interest in the potential advantages of integrated crop-livestock systems in combatting climate change and improving resilience in agricultural production (van Wijk, 2020). This includes agroforestry practices such as silvopastoralism (Moreno and Rolo, 2019). Areas have been shown to produce more edible plant material and more meat or milk when trees and shrubs with edible, high protein leaves as well as pasture plants are grown in semi-intensive silvopastoral systems than pasture-only systems (Murgueitio et al 2008, Broom et al 2013, Broom 2017b). In some parts of the world where climate would be favourable, dairy cattle could, for example, be managed on pastures with shrubs such as *Leucaena leucocephala* (Radrizzani et al 2016). Cut leafy branches of trees such as ramón *Brosimum alicastrum* can be an important source of food where there is a dry season (Ku Vera et al 2013). Other benefits are that biodiversity is much higher in semi-intensive silvopastoral systems than in pasture-only systems, with more tick and fly predators so reducing cattle disease, as well as the potential to better conserve forest resources (Burgess 1999, Múnera et al 2008, Rivera et al 2008, McAdam and McEvoy 2009, Sutherland et al 2018).

4 Conclusion

This chapter has highlighted some of the key welfare issues faced by the dairy sector. It has placed these challenges within the broader framework of the sustainability of the sector which is under growing scrutiny. It is important to emphasise that, whilst there are some serious welfare problems at present, in several systems dairy cows and calves can be produced with very good welfare. Retailers and all who buy dairy products should insist on seeing evidence for high welfare standards. Whether it is welfare or environmental impact, transparency is essential. Consumers need to obtain accurate information. The best dairy production systems use resources that cannot

easily be used in any other way for food production, have no negative impacts on animal welfare and have no greater negative impact on the environment than wholly plant-based alternatives. Much change in the industry is needed in order to find and use the best production methods to achieve these challenging goals.

5 Where to look for further information

A comprehensive review of dairy cow welfare by a group of independent scientists is that by the European Food Safety Authority (EFSA) (2009). Some other aspects of sustainability are reviewed by De Jong (2013) and Balmford et al. (2018).

6 References

Archer, S.C., Green, M.J. and Huxley, J.N. (2010) Association between milk yield and serial locomotion score assessments in UK dairy cows. *J. Dairy Sci*., 93, 4045-4053.

Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., Field, R., Garnsworthy, P., Green, R., Smith, P., Waters, H., Broom, D.M., Chará, J., Finch, T., Garnett, E., Gathorne-Hardy, A., Hernandez-Medrano, J, Herrero, M., Hua, F., Latawiec, A., Misselbrook, T., Phalan, B., Simmons, B., Takahashi, T., Vause, J., zu Ermgassen, E. and Eisner, R. (2018). The environmental costs and benefits of high-yield farming. *Nature Sustainability,* 1, 477- 485. doi 10.1038/s41893-018-0138-5

Barker, Z.E., Leach, K.A., Whay, H.R., Bell, N.J. and Main, D.C.J. (2010) Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales. *J. Dairy Sci.,* 93, 932-941.

Bell, N. (2017). Preventing and managing lameness in dairy cows. In Webster, J. (ed). *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Bennett, R.M., Anderson, J. and Blaney, R.J.P. (2002). Moral intensity and willingness to pay concerning farm animal welfare issues and the implications for agricultural policy. *J. Agric. Environ. Ethics,* 15, 187–202.

Berglund, B., (2008). Genetic improvement of dairy cow reproductive performance. *Reproduction in domestic animals*, *43*, pp.89-95. doi.org/10.1111/j.1439-0531.2008.01147.x

Blümmel. M., Muller, A., Schader, C., Herrero, M.T. and Garg, M.R., (2018). The use and abuse of cereals, legumes and crop residues in rations for dairy cattle. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Boe, K. E. and Faerevik, G. (2003). Grouping and social preferences in calves, heifers and cows. *Appl. Anim. Behav. Sci.,* 80, 175-190.

Bran, J.A., Costa, J.H., von Keyserlingk, M.A. and Hötzel, M.J. (2019). Factors associated with lameness prevalence in lactating cows housed in freestall and compost-bedded pack dairy farms in southern Brazil. *Prev. Vet. Med.* 172, doi:10.1016/j.prevetmed.2019.104773.

Broom, D.M. (1996). Scientific research on veal calf welfare. In: *Veal Perspectives to the Year 2000. Proceedings of International Symposium, Le Mans, France.* Fédération de la Vitellerie Francaise, Paris, pp. 147–153.

Broom, D.M. (2001). The use of the concept animal welfare in European conventions, regulations and directives. In *Food Chain* pp.148-151, SLU Services, Uppsala.

Broom, D.M. (2010). Animal welfare: an aspect of care, sustainability, and food quality required by the public. *J. Vet. Med. Educ.* 37, 83-88. doi: 10.3138/jvme.37.1.83

Broom, D.M. (2013). Cow welfare and herd size: towards a sustainable dairy industry. *Cattle Practice.,* 21, 169-173.

Broom, D.M. (2014). *Sentience and Animal Welfare.* pp. 200, Wallingford: CABI.

Broom, D.M. (2017). *Animal Welfare in the European Union,* (pp75), European Parliament Policy Department: Brussels, Belgium. ISBN: 978-92-846-0543-9.

Broom, D.M. (2017). Components of sustainable animal production and the use of silvopastoral systems. *Rev. Bras. Zootec., 46*, 683–688, doi:10.1590/s1806-92902017000800009.

Broom, D.M. (2018). Animal welfare and the brave new world of modifying animals. In *Are we Pushing Animals to their Biological Limits?* T. Grandin and M. Whiting (eds), 172-180. Wallingford: CABI.

Broom, D.M. (2018). The scientific basis for action on animal welfare and other aspects of sustainability. In *Farming, Food and Nature: Respecting Animals, People and the Environment*, D'Silva, J., McKenna, C., Eds.; Earthscan: London, UK; Routledge: New York, NY, USA, pp. 93–100, ISBN: 9781138541443.

Broom, D.M. (2019). Land and water usage in beef production systems. *Animals,* 9(6), 286. doi:10.3390/ani9060286

Broom, D.M. and Fraser, A.F. (2015). *Domestic Animal Behaviour and Welfare, 5th edn. (pp 472).* Wallingford: CABI.

Broom, D.M., Galindo, F.A. and Murgueitio, E. (2013). Sustainable, efficient livestock production with high biodiversity and good welfare for animals. *Proc. Roy. Soc. B., 280, 20132025.* doi.org/10.1098/rspb.2013.2025

Broom, D.M. and Leaver, J.D. (1978). The effects of group-housing or partial isolation on later social behaviour of calves. Anim. Behav., 26, 1255–1263.

Burgess PJ. 1999 Effects of agroforestry on farm biodiversity in the UK. *Scot. Forestry,* 53, 24 – 27.

Charlton, G. L., Rutter, S.M., East, M. and Sinclair, L.A. (2011). Effects of providing total mixed rations indoors and on pasture of the behavior of lactating dairy cattle and their preference to be indoors or on pasture. *J. Dairy Sci.,* 94, 3875-3884.

Charlton, G. L., Rutter, S.M., East, M. and Sinclair, L.A. (2012). The motivation of dairy cows for access to pasture. *J. Dairy Sci.,* 96, 4387-4396.

Compton, C.W.R., Heuer, C., Thomsen, P.T., Carpenter, T.E., Phyn, C.V.C. and McDougall, S., (2017). Invited review: A systematic literature review and meta-analysis of mortality and culling in dairy cattle. *J. Dairy Sci.*, *100*, 1-16.

Cook, N.B., Hess, J.P., Foy, M.R., Bennett, T.B., Brotzman, R.L. (2016). Management characteristics, lameness, and body injuries of dairy cattle housed in high-performance dairy herds in Wisconsin. *J. Dairy Sci*., 99: 5879-5891.

Diskin, M. G., Waters, S.M., Parr, M.H. and Kenny, D.A. (2016). Pregnancy losses in cattle: potential for improvement. *Reprod. Fertil. Dev.* 28: 83-93.

Dobson, H., Smith, R.F., Royal, M.D., Knight, C.H. and Sheldon, I.M., 2007. The high-producing dairy cow and its reproductive performance. *Reproduction in domestic animals*, *42*, 17-23. doi.org/10.1111/j.1439-0531.2007.00906.x

EFSA (2009). Scientific report on the overall effects of farming systems on dairy cow welfare and disease. *Annex to the EFSA Journal*, 1143, 1-38.

Esslemont, R.J. and Kossaibati, M.A. (1997) Culling in 50 dairy herds in England. *Veterinary Record* 140, 36–39.

EU SCAHAW (1999). *EU Scientific Committee on Animal Health and Animal Welfare Report on animal welfare aspects of the use of bovine somatotrophin.* European Commission, Brussels.

Evans, A. and Zeng, S. (2018). Causes, prevention and management of infertility in dairy cows. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Friggens, N.C., Disenhaus, C. and Petit, H.V., 2010. Nutritional sub-fertility in the dairy cow: towards improved reproductive management through a better biological understanding. *Animal*, *4*(7), 1197-1213. doi.org/10.1017/S1751731109991601

Gaillard, C., Meagher, R. K., von Keyserlingk, M. A., and Weary, D. M. (2014). Social housing improves dairy calves' performance in two cognitive tests. *PloS one*, *9*, e90205

(6 pages).

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J. et al. (2010). Smart investments in sustainable food production: Revisiting mixed crop-livestock systems. *Science*, *327*, 822–825, doi:10.1126/science.1183725.

Jamali, H., Jamali, H., Barkema, H.W., Jacques, M., Lavallée-Bourget, E.M., Malouin, F., Saini, V., Stryhn, H. and Dufour, S. (2018). Invited review: Incidence, risk factors and effect of clinical mastitis recurrence in dairy cows. *J. Dairy Sci.* 101(6): 4729-4746.

Knaus, W. (2009). Dairy cows trapped between performance demands and adaptability. *J. Sci. Food Agric*, 89, 1107-1114.

Ku-Vera, J.C., Ayala-Burgos, A.J., Solorio-Sánchez, F.J., Briceño-Poot, E.G., Ruiz-González, A., Piñeiro-Vázquez, A.T., Barros-Rodríguez, M., Soto-Aguilar, A., Espinoza-Hernández, J.C., Albores-Moreno, S. and Chay-Canul, A.J., (2013). Tropical tree foliages and shrubs as feed additives in ruminant rations. *Nutritional Strategies of Animal Feed Additives.* Nova Sci. Publishers. New York. USA, pp.59-76.

Legrand, A.L., von Keyserlingk, A.G. and Weary, D.M. (2009). Preference and usage of pasture versus free-stall housing by lactating dairy cattle. *J. Dairy Sci.,* 92, 3651-3658.

Leroy, J.L., Valckx, S.D., Jordaens, L., De Bie, J., Desmet, K.L., Van Hoeck, V., Britt, J.H., Marei, W.F. and Bols, P.E., (2015). Nutrition and maternal metabolic health in relation to oocyte and embryo quality: critical views on what we learned from the dairy cow model. *Reproduction, Fertility and Development*, *27*(4), pp.693-703. doi.org/10.1071/RD14363

Marshall, A. and Collins, R. (eds) (2018). *Improving grassland and pasture management in temperate agriculture*, Burleigh Dodds Science Publishing.

McAdam JH and McEvoy PM. (2009). The potential for silvopastoralism to enhance biodiversity on grassland farms in Ireland. In *Agroforestry in Europe: current status and future prospects* (eds A Rigueiro-Rodriguez, J McAdam, MR Mosquera-Losada), pp. 343 – 356. Berlin, Germany: Springer.

Miller-Cushon, E., Leslie, K. and DeVries, T. (2018). Ensuring the health and welfare of dairy calves and heifers. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare,*149. Burleigh Dodds Science Publishing, Cambridge, UK.

Moreno, G. and Rolo, V. (2019). Agroforestry practices: silvopastoralism. In Mosquera-Losada, M. and Prabhu, R. (eds), *Agroforestry for sustainable agriculture*, Burleigh Dodds Science Publishing, Cambridge, UK.

Moroni, P. (2017). Mastitis, milk yield and quality. In van Belzen, N. (ed.), *Achieving sustainable production of milk Volume 1: Safety, quality and sustainability*. Burleigh Dodds Science Publishing, Cambridge, UK.

Moroni, P. (2018). Aetiology, diagnosis and control of mastitis in dairy herds. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Múnera E, Bock BC, Bolivar DM, Botero JA. (2008). Composición y estructura de la avifauna en diferentes hábitats en el departamento de Córdoba, Colombia. In *Ganadería del Futuro* (eds E Murgueitio, CA Cuartas, JF Naranjo), pp. 205–225. Cali, Colombia: Fundacio´n CIPAV.

Murgueitio, E., Cuartas, C.A. and Naranjo, J.F. 2008. *Ganadería del Futuro,* Fundación CIPAV, Cali Colombia.

Oltenacu, P.A. and Broom, D.M. (2010). The impact of genetic selection for increased milk yield on the welfare of dairy cows. *Anim. Welfare,* 19 (S), 39-49.

Penner, G. (2018). Disorders of digestion and metabolism in dairy cattle: the case of subacute rumen acidosis. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Phillips, C.J.C. (2002). *Cattle Behaviour and Welfare, 2nd edn.* Blackwell Scientific, Oxford, U.K.

Phillips, C. (2018). Understanding the behaviour of dairy cattle. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Plaizier, J.C.B., Lissemore, K.D., Kelton, D. and King, G.J. (1998). Evaluation of overall reproductive performance of dairy herds. *J. Dairy Sci.,* 81, 1848–1854.

Polsky, L. and von Keyserlingk, M.A.G. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *J. Dairy Sci.*, 100, 8645–8657. doi:10.3168/jds.2017-12651.

Pryce, J. and de Haas, Y. Genetic selection for dairy cow welfare and resilience to climate change. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Radrizzani, A., Shelton, H. M., Kravchuk, O. and Dalzell, S. A. (2016). Survey of long-term productivity and nutritional status of *Leucaena leucocephala*-grass pastures in subtropical Queensland. *Anim. Prod. Sci.*, *56* 12: 2064-2073. doi:10.1071/AN15084.

Ranjbar, S., Rabiee, A.R., Gunn, A. and House, J. K. (2016). Identifying risk factors associated with lameness in pasture-fed dairy herds. *J. Dairy Sci.* 99, 7495-7505.

Rivera LB, Botero M, Escobar S, Armbrecht I. (2008). Diversidad de hormigas en sistemas ganaderos. In Ganadería del Futuro (eds E.Murgueitio,C.A.Cuartas, J.F. Naranjo), pp. 228 – 243. Cali, Colombia: Fundación CIPAV.

Robbins, JA, von Keyserlingk, MAG, Fraser, D, Weary, DM (2016). Invited review: Farm size and animal welfare. *J. Anim. Sci.* 94(12): 5439–5455.

Rushen, J. (2018). Housing and the welfare of dairy cattle. In Webster, J. (ed), *Achieving sustainable production of milk Volume 3: Dairy herd management and welfare*. Burleigh Dodds Science Publishing, Cambridge, UK.

Sant'Anna, A.C. and Paranhos da Costa, M.J.R. (2011). The relationship between dairy cow hygiene and somatic cell count in milk*. J. Dairy Sci.*, *94*, 3835–3844, doi:10.3168/jds.2010-3951.

Schukken, Y.H., Tikofsky, L.L. and Zadoks, R.N. (2005). Environmental control for mastitis prevention, milk quality and food safety. In *Mastitis in Dairy Production: Current Knowledge and Future Solutions*; Hogeveen, H., Ed.; Wageningen Academic Publishers: Wageningen, The Netherlands, 109–114.

Scott, N. and Gooch, C. (2017). 'Towards' sustainability of dairy farming: an over Invan Belzen, N. (ed), *Achieving sustainable production of milk Volume 2: Safety, quality and sustainability*. Burleigh Dodds Science Publishing, Cambridge, UK.

Spörndly, E. and Wredle, E. (2004). Automatic milking and grazing – Effects of distance to pasture and level of supplements on milk yield and cow behavior. *J. Dairy Sci.*, 87, 1702-1712.

Stafford, K.J. and Mellor, D.J. (2005). Dehorning and disbudding distress and its alleviation in calves - a review. *Vet. J.,* 169, 337–349.

Stilwell, G, Carvalho, R.C., Carolino, N., Lima, M.S. and Broom, D.M. (2010). Effect of hot-iron disbudding on behaviour and plasma cortisol of calves sedated with xylazine. *Res. Vet. Sci.,* 88, 188-193.

Stilwell, G. Carvalho, R.C., Lima, M.S. and Broom, D.M. (2009). Effect of caustic paste disbudding, using local anaesthesia with and without analgesia, on behaviour and cortisol of calves. *Appl. Anim. Behav. Sci*., 116, 35-44.

Stilwell, G.T., Ferrador, A.M., Santos, M.S., Domingues, J.M. and Carolino, N., (2019). Use of topical local anesthetics to control pain during treatment of hoof lesions in dairy cows. *J. Dairy Sci.*, *102*, 6383-6390.

Stilwell, G., Lima, M.S. and Broom, D. M. (2008). Effects of nonsteroidal anti-inflammatory drugs on long-term pain in calves castrated by use of an external clamping technique following epidural anaesthesia. *Amer. J. Vet. Res.* 69, 744-750.

Stilwell, G., Lima, M.S. and Broom, D.M. (2008). Comparing plasma cortisol and behaviour of calves dehorned with caustic paste after non-steroidal-anti-inflammatory

analgesia. *Livest. Sci*., 119, 63-69.

Stilwell, G., Lima, M.S., Carvalho, R.C. and Broom, D.M. (2012). Effects of hot-iron disbudding, using regional anaesthesia with and without carprofen, on cortisol and behaviour of calves. *Res. Vet. Sci.,* 92, 338-341.

Stilwell, G., Schubert, H. and Broom, D.M. (2014). Effects of analgesic use post-calving on cow welfare and production. *J. Dairy Sci.,* 97, 888-891.

Stoll-Kleemann, S. and O'Riordan, T., (2015). The sustainability challenges of our meat and dairy diets. *Environment: Sci. Policy Sustain. Dev.*, *57*, 34-48.

Sutherland, W.J., Dicks, L.V., Everard, M. and Geneletti, D., (2018). Qualitative methods for ecologists and conservation scientists. *Methods Ecol. Evol.*, *9*, 7-9.

Van Wijk, M. (2020). The contribution of integrated crop-livestock systems in combatting climate change and improving resilience in agricultural production. In Deryng, D. (ed.), *Climate change and agriculture*, Burleigh Dodds Science Publishing, Cambridge, UK.

Veissier, I., Gesmier, V., Le Neindre, P., Gautier, J.Y. and Bertrand, G. (1994). The effects of rearing in individual crates on subsequent social behaviour of veal calves. *Appl. Anim. Behav. Sci.* 41, 199–210.

Von Keyserlingk, M.A., Cestari, A.A., Franks, B., Fregonesi, J.A. and Weary, D.M., 2017. Dairy cows value access to pasture as highly as fresh feed. *Sci. Rep.*, *7*, p.44953.

Von Keyserlingk, M.A.G., Martin, N.P., Kebreab, E., Knowlton, K.F., Grant, R.J., Stephenson, M., Sniffen, C.J., Harner, J.P., Wright, A.D. and Smith, S.I., (2013). Invited review: Sustainability of the US dairy industry. *J. Dairy Sci.*, *96*, 5405-5425.

Von Keyserlingk, M.A.G., Rushen, J., de Passillé, A.M. and Weary, D.M. (2009). Invited review: The welfare of dairy cattle—Key concepts and the role of science. *J. Dairy Sci.* 292, 4101–4111. doi:10.3168/jds.2009-2326.

Woodfield, D. and Judson, H. (2018). Balancing pasture productivity with environmental and animal health requirements. In Marshall A. and Collins, R. (eds), *Improving grassland and pasture management in temperate agriculture*, Burleigh Dodds Science Publishing, Cambridge, UK.

Woolf, J. (2020). Quantifying the role of livestock in climate change. In Deryng, D. (ed.), *Climate change and agriculture*, Burleigh Dodds Science Publishing, Cambridge, UK.