Revista Científica, FCV-LUZ / Vol. XXXIII, Supl. Esp., 117 - 123, 2023, https://doi.org/10.52973/rcfcv-wbc018

SUSTAINABILITY AND LIVESTOCK: A DOABLE COMBINATION

Sostenibilidad y ganadería: una combinación factible

Antonella Chiariotti

Council for Agricultural Research and Economics (CREA) – Research Center for Animal Production and Aquaculture, Rome, Italy
**Corresponding e-mail: Chiariotti, Antonella (antonella.chiariotti@crea.gov.it).*

ABSTRACT

Sustainable development means meeting the needs of the present while ensuring future generations can meet their own needs (European Commission). Rapid urbanization, increased purchasing power, and dietary change drive demand for richer diets and animal-origin proteins, leaving more than 868 million undernourished citizens worldwide and 850 million living in developing countries. Food security could be granted to large populations by reducing food waste, which accounts for 1.3 billion tons per year, or implementing livestock farming and promoting a sustainable food demand. With economic progress and the world's growing population, estimated to reach more than 9 billion people in 2050, animal proteins will increase as meat and milk demand. Nevertheless, ruminants produce methane, which accounts for most of the agricultural sector emissions (5.8% of the total anthropogenic), raising concerns about their production. If ruminant livestock increase, methane production increases, accelerating global warming inevitably. Depending on resource quality, environmental factors, and social and economic contexts, various types of livestock production systems may vary considerably in sustainability. These livestock systems include extensive grassland, intensive landless, mixed, and family farming systems. Massive worldwide research has investigated the effect of various mitigation strategies. Nonetheless, the under-representation of certain strategies, geographic regions, the calculation's robustness, and long-term studies are the main limitations in providing an accurate quantitative estimation of the respective mitigation potential under diverse animal production systems. Ruminant livestock is important not only for producing nutrient-dense meat and milk for human diets but also for providing hides, fiber, manure, and animal power for farming and transportation in many countries and contributing to biodiversity. To obtain this, they eat grass and legume plants that would be inedible to humans or live on land unsuitable for cultivation. Livestock also contributes to much-needed income for family farmers in developing countries. The buffalo (Bubalus bubalis), represented by a total of 204 million head (3.9 % increase in the last ten years), could play a strategic role due to its peculiar characteristics: the high ability to convert fiber into energy, the longevity, and the adaptation in extreme areas with cold or hot-humid climate where other ruminants cannot thrive. Moreover, it contributes to the sustenance of many people living in rural areas. A multidisciplinary approach considering the environment, animal health and welfare, and social and economic contexts is requested to increase the sustainability of livestock.

Keywords: sustainability, buffalo, climate change, mitigation strategies.

RESUMEN

El desarrollo sostenible significa satisfacer las necesidades del presente y al mismo tiempo garantizar que las generaciones futuras puedan satisfacer sus propias necesidades (Comisión Europea). La rápida urbanización, el aumento del poder adquisitivo y los cambios en la dieta impulsan la demanda de dietas más ricas y proteínas de origen animal, lo que deja a más de 868 millones de ciudadanos desnutridos en todo el mundo y a 850 millones viviendo en países en desarrollo. Se podría garantizar la seguridad alimentaria a grandes poblaciones reduciendo el desperdicio de alimentos, que representa 1.300 millones de toneladas al año, o implementando la ganadería y promoviendo una demanda alimentaria sostenible. Con el progreso económico y la creciente población mundial, que se estima alcanzará los 9 mil millones de personas en 2050, las proteínas animales aumentarán a medida que la demanda de carne y leche. Sin embargo, los rumiantes producen metano, que representa la mayor parte de las emisiones del sector agrícola (5,8% del total antropogénico), lo que genera preocupación sobre su producción. Si aumenta el ganado rumiante, aumenta la producción de metano, acelerando inevitablemente el calentamiento global. Dependiendo de la calidad de los recursos, los factores ambientales y los contextos sociales y económicos, la sostenibilidad de varios tipos de sistemas de producción ganadera puede variar considerablemente. Estos sistemas ganaderos incluyen pastizales extensivos, sistemas de agricultura intensiva sin tierra, mixtos y familiares. Una investigación masiva a nivel mundial ha investigado el efecto de varias estrategias de mitigación. No obstante, la subrepresentación de ciertas estrategias, regiones geográficas, la solidez de los cálculos y los estudios a largo plazo son las principales limitaciones para proporcionar una estimación cuantitativa precisa del potencial de mitigación respectivo en diversos sistemas de producción animal. El ganado rumiante es importante no sólo por producir carne y leche ricas en nutrientes para la dieta humana, sino también por proporcionar pieles, fibras, estiércol y energía animal para la agricultura y el transporte en muchos países y contribuir a la biodiversidad. Para obtenerlo, comen pastos y leguminosas que no serían comestibles para los humanos o viven en tierras no aptas para el cultivo. La ganadería también contribuye a unos ingresos muy necesarios para los agricultores familiares de los países en desarrollo. El búfalo (*Bubalus bubalis*), representado por un total de 204 millones de cabezas (un aumento del 3,9 % en los últimos diez años), podría desempeñar un papel estratégico por sus peculiares características: la alta capacidad de convertir la fibra en energía, la longevidad y la adaptación en zonas extremas con clima frío o cálido-húmedo donde otros rumiantes no pueden prosperar. Además, contribuye al sustento de muchas personas que viven en zonas rurales. Se requiere un enfoque multidisciplinario que considere el medio ambiente, la salud y el bienestar animal y los contextos sociales y económicos para aumentar la sostenibilidad de la ganadería.

Palabras clave: sostenibilidad, búfalo, cambio climático, estrategias de mitigación.

INTRODUCTION

The Global Agenda for Sustainable Livestock (GASL) defines sustainable livestock as follows: “To be sustainable, livestock sector growth needs to simultaneously address key environmental, social, and economic challenges: growing natural resources scarcity, climate change, widespread poverty, food insecurity and global threats to animal and human health and animal welfare”. Sustainable livestock solutions are driven by two significant elements: the sector’s diversity and the demand for livestock commodities [1].

According to FAO estimates, the livestock sector accounts for 40% of the agricultural gross domestic product in a significant part of South Asia and sub-Saharan Africa, occupying 33% of the world’s land and supporting more than 1 billion people who depend on pastoralism for food and livelihood and providing more than 25% of the world’s protein intake [2].

The world’s growing population will reach more than 9 billion people in 2050, and an improved standard of living will inevitably increase demands for animal proteins (meat and milk). Nevertheless, ruminants produce methane, which accounts for most of the agricultural sector emissions (5.8% of the total anthropogenic), raising concerns about their production. If ruminant livestock increase, methane production increases, accelerating global warming in the process.

To obtain a vast range of food and services, livestock use vegetable resources that would be inedible to humans and/or live on land unsuitable for cultivation. Moreover, rearing livestock also offers much-needed income for small-scale farmers in developing nations. Ruminants, especially when fed with feedstuff produced on land unsuitable for primary cropping or by-products from agro-industrial, can be a net contributor to procuring human edible food [3]. Moreover, they maintain and enhance protein and essential micronutrient supply (Zinc, calcium, Vit.B12, and riboflavin), often challenging to obtain from vegetable crops [4, 5].

The livestock sector faces numerous challenges, such as climate change, water depletion, desertification, and land erosion. Even though it may have contributed to enhancing some of these issues, it can contribute to the solution, operating within an agroecological and environmental framework while protecting biodiversity [6]. The livestock sector relates also to the importance of different ecosystem types, management methods, and local needs and traditions. In fact, livestock products and production systems are different, and they span from intensive to extensive, from cold to tropical, and from highly technological to local traditional. The most suitable approaches depend on the context and cannot be integrated into one global model [7].

Among ruminants, with a total of 204 million head (a 3.9 % increase in the last ten years), buffalo (*Bubalus bubalis*) could contribute to sustainability for its specie-specific characteristics: its high ability to convert row fiber into energy, its rusticity, its ability to adapt to different climatic environments (cold, tropical, or swampy), and its longevity, which is always higher than cattle.

CONCERNS ABOUT LIVESTOCK

There is a growing concern that the demand for animal products, associated with population growth, prolonged lifespan, and improved economic welfare, particularly in developing countries, will put an unsustainable call on the environment [8].

It also must be considered that animal production yields highly heterogeneous categories of foods (i.e., dairy, meats, eggs), each produced differently, displaying its own biochemical and nutritional properties, produced in regions with different ecological contexts, and consumed by populations with specific nutritional, economic, and cultural needs. So, animal-source food intake substantially differs between geographical regions and socioeconomic categories.

In the general debate, the complexity of the food system is often neglected and reduced to three interconnected claims that consumption of animal-source foods causes harm to human health, to the planet, and the animal itself related to health

FIGURE 1. Graphical abstract

hazards, climate change, and animal welfare [5], forgetting that livestock sustains the livelihood of millions of people in the world (up to 12%), both in developing and developed countries.

CLIMATE CHANGE

Methane is a greenhouse gas (GHG) far less abundant than CO_2 but with a global warming potential 28 times more potent on a 100-year scale [9]. Methane derives from the balance between sources and sinks. Sources are biogenic (i.e., wetlands, agriculture, waste/landfill, permafrost), thermogenic (i.e., fossil fuel), pyrogenic (biomass and biofuel burning), or mixed sources, while the sink is mainly methane oxidation in soil [10].

Agriculture contributes with a percentage varying from 8 to 18% of total anthropogenic GHG emissions. Feed production, land use change, energy (not only as farm inputs and feed, but other activities such as animal housing and ventilation), and product processing are included in most global estimates. Livestock mainly contributes by enteric fermentation, manure as methane and nitrous oxide, and different manure management systems generate different emissions levels. Among ruminants-related direct emissions, cattle are responsible for 65% and buffaloes for 8% [11].

Climate change can increase extreme weather conditions that directly and indirectly affect livestock productivity (TABLE I). Due to the increase in temperatures, livestock production is experiencing reduced growth and reproductive efficiency, reduced milk and meat production, and animal health, making them vulnerable to new diseases. Fodder and water supplies are also affected by climate extremes and seasonal variations.

Global food security is threatened by climate change and its adverse impact on livestock production.

HOW TO COPE WITH CLIMATE CHANGE

For a livestock production "climate-smart", the two possible approaches are adapting to climatic changes and mitigating GHG [12]. Integrating these two aspects can exploit synergies and minimize trade-offs between mitigation and adaptation.

Adaptation approaches might include promoting resilient livestock production, modifying production and management systems, scientific and technological improvements, governance and policy changes, and changing farmers' perceptions and adaptive capacity [13]. Adaptation measures should incorporate agroecological principles (e.g., improved circularity) while limiting feed-food competition. However, they should also remain respectful of the diversity of ecosystem contexts, the availability of resources, and the various social and economic needs of local populations [6].

Feed sources with increased drought-tolerant producing more biomass and being more resilient to environmental extremes, could be more sustainable. Moreover, genetic improvement can select livestock with greater heat tolerance and less energy requirements, which might help ensure their performances so production is less affected [14]. There are more than 40 species of farmed animal species and more than 8,800 local breeds adapted to specific contexts [15], and due to their greater ability to thrive in a stressful environment, indigenous breeds display higher resilience than exotic breeds.

MITIGATION STRATEGIES

Microbial fermentations in the rumen play an essential role in the ability of ruminants to utilize lignocellulosic materials to produce volatile fatty acids (VFAs) and to convert non-protein nitrogen into microbial protein, which is an essential source of energy and protein for the host. In contrast, the rumen provides the microbes with a suitable environment to thrive and grow [16]. Nevertheless, microbes also have potential environmental detrimental effects through methane emission and excessive nitrogen excretions in feces and urine. Rumen methane production also represents energy loss (from 2 to 12% of gross energy intake) for animal growth and production [17].

A massive worldwide research effort has been devoted to finding successful mitigation strategies that can be summarized into three categories (TABLE II): changes in animal and feed management, diet formulation, and rumen manipulation [18,19,20,21,22].

All of them potentially involve changes in the rumen microbiome [23], thus lowering methane emissions, which would benefit the environment and, eventually, the livestock production efficiency. Nevertheless, according to Arndt et al. (2022), methane yield is not the only relevant measure; other methane emissions and animal performance metrics should be considered to estimate the feasibility of mitigation strategies.

SUSTAINABLE MANAGEMENT

Well-managed livestock are an integral and productive part of agriculture. Among other ecological services, they can convert non-edible biomass from pasture systems and produce human food, recycle plant nutrients back into the soil, improve soil health, and sequester carbon [6].

Integrating crop and livestock farming is an effective strategy to reduce emissions associated with animal production [24]. Agroforestry systems (i.e., silvopastoral), where trees and meadows are combined, can reward farmers financially while improving yields and reducing the environmental burden. In addition, research has shown that pasture-based production systems are better for animal welfare and enhance biodiversity, as these systems allow for more natural animal behavior.

Grazing management and soil management practices include rotational grazing, cover cropping, and conservation tillage. Rotational grazing involves altering grazing patterns to ensure that the plants are not overgrazed and have time to regrow. In contrast, cover cropping involves the planting of specific species of crops after harvesting to add fertility to the soil while conserving soil moisture and reducing erosion. Conservation tillage involves minimal mechanical disturbance of the soil. It helps retain a large portion of the crop residues on the soil surface to be used as organic matter for soil nutrition. Practices such as rotational grazing and fodder banking can also increase the production efficiency of smallholder farms and prevent land degradation. These methods reduce methane emissions from the soil, along with reducing erosion and water pollution [25]. Nevertheless, adopting the best sustainable farming systems is often complex as they could result in different outcomes, favoring, in some cases, biodiversity conservation and carbon sequestration or, in some others, privileging

TABLE I
CLIMATIC CHANGE IMPACT ON LIVESTOCK PRODUCTION

Impact	Observed Impact	Causes
Direct	- Feed intake - Milk and meat production - Reproductive performance - Immune functions + Mortality	+ Temperature (heat stress)
Indirect	- Crop yield Change in pasture composition	> CO_2 concentrations
	Change in forage quality	+ Temperature > CO_2 concentrations
	Seasonal changes in resource supply	> Frequent extreme weather events
	- Water availability + Water consumption	+ Temperature
	+ Diseases, pests, and stress	+ Temperature change in rainfall frequency

Modified Cheng et al., 2022

TABLE II
MITIGATION STRATEGIES FOR THE REDUCTION OF METHANE IN RUMINANTS

Mitigation strategies		
Animal and feed management	Diet formulation	Rumen manipulation
Genomic selection	Forage quality	Vaccination
Rational grazing	Lipids	Defaunation
Agroforestry	Sea weeds	Direct-fed microbial
Animal health	Additives	
Manure management		

production [26]. For example, systems based on grazing may show higher environmental performances because of the lower inputs needed for production, albeit requiring more land.

Swapping traditional animal feeds with more carbon-friendly ones could help [27]. For instance, soybean meal and maize are incredibly carbon-intensive due to the large amounts of inputs needed to produce them. Alternatives such as barley, alfalfa, or sorghum are more sustainable. Furthermore, some livestock farms are now using by-products from agro-industrial residues that could help reduce waste and their disposal costs.

Knowledge about management and information sharing among farmers are also substantial interventions for sustainable livestock production. Access to accurate and timely information can increase farmers' capacity to manage their resources, leading to improved yields and reduced emissions [28].

INNOVATIVE TECHNOLOGIES

Research and governance have been exploring recent innovations in sustainable livestock production to respond to climate challenges, maintaining the environment and an efficient food system. Innovations in different fields can open new solutions, such as smart farming, genetics, robotics, environmental monitoring, and developing new business models [29]. Advances in informatics allowed the advancement of cameras, sensors, and environmental technologies. Moreover, networking and farm management software allow farmers to improve animal management on individual needs to make informed decisions. Through these techniques, for example, farmers can monitor soil fertility and reduce the input of fertilizers to maintain soil health.

Sustainable livestock production can utilize renewable energy sources to reduce carbon emissions and produce green energy for the farm, thus reducing reliance on fossil fuel sources [30]. Some farms are now utilizing solar power, wind turbines, and biogas digesters to power their operations to save on operational costs, thus reducing the emissions associated with farming [31].

BUFFALO IS A TOOL FOR SUSTAINABILITY

The buffalo (*Bubalus bubalis*), a species represented by more than 204 million heads worldwide, plays a strategic role in the world economy and society. One characteristic that makes the buffalo so widely used is its ability to convert fiber into energy. Numerous studies indicate the superiority of buffalo over cattle in food conversion and using fodder and agricultural by-products with low nutrient content [32]. In addition, from a recent molecular study, buffalo rumen, compared to bovine rumen, appears to have a greater potential for fiber degradation and less potential for gastroenteric methane production [33]. Other important characteristics of the buffalo are its rusticity, ability to adapt to different climatic environments (from hot-humid to very cold), and longevity, which is always higher than that of the bovine. Buffalo is suitable for work in plantations or wetlands due to its broad articulation in the hoofs, especially during the rainy period, when the muddy soil causes difficult mobility for other species. For this characteristic, the buffalo became many countries' best draught power animal option.

It should be emphasized that this goes hand in hand with buffalo products of high quality. Buffalo meat has a lower calorie content, lower cholesterol, an unsaturated fatty acid/saturated fatty acid ratio >1, a higher protein level, and a higher iron content (>1.5mg/100g) compared to beef [34]. Buffalo milk also plays a vital role in human nutrition, especially in developing countries. It is richer than cow's milk in all major constituents, such as fat (6.6-8.8%), lactose (4.5-5.2%), protein (3.8-4.5%), casein, and ash [35]. These chemical characteristics also allow for a cheese yield twice as high as that usually obtained with cow's milk. Furthermore, the presence of the A2 versus A1 variant of β-casein makes this milk more like human breast milk and, therefore, probably easier to digest [36].

CONCLUSIONS

A multidisciplinary approach embracing the more comprehensive and varied aspects of nutrition, landscapes, and culture considering the environment, livestock management, animal health and welfare, and social factors is requested to deal with the environmental issues of livestock. There is a considerable margin for correcting and improving livestock production that can substantially decrease the environmental burden and advances in animal welfare. The optimal quantity of animal-source foods in the diet of different populations will depend on health, environmental, and social factors as well as management methods that vary considerably and are challenging to bring down to simple metrics. In conclusion, when livestock production is done well, respecting local ecosystems and social contexts, it could improve public health and environmental resilience.

REFERENCES

[1] Schneider F, Tarawali S. Sustainable Development Goals and livestock systems. Revue Scientifique et Technique (International Office of Epizootics). 2021 Aug 1;40(2):585-95.

[2] Food and Agriculture Organization of the United Nations (FAO). Livestock and Landscapes: Sustainability Pathways. Food and Agriculture Organizations of the United Nations. Available online: https://www.fao.org/3/ar591e/ar591e.pdf (accessed in November 2023.

[3] Van Zanten HH, Herrero M, Van Hal O, Röös E, Muller A, Garnett T, Gerber PJ, Schader C, De Boer IJ. Defining

a land boundary for sustainable livestock consumption. Global change biology. 2018 Sep;24(9):4185-94.

[4] Scollan ND, Hocquette JF, Richardson RI, Kim EJ. Raising the nutritional value of beef and beef products to add value in beef production. Nutrition and climate change: major issues confronting the meat industry (ed. JD Wood and C Rowlings). 2011 Apr 1:79-104.

[5] Leroy F, Smith NW, Adesogan AT, Beal T, Iannotti L, Moughan PJ, Mann N. The role of meat in the human diet: evolutionary aspects and nutritional value. Animal Frontiers. 2023 Apr 1;13(2):11-8.

[6] Thompson L, Rowntree J, Windisch W, Waters SM, Shalloo L, Manzano P. Ecosystem management using livestock: embracing diversity and respecting ecological principles. Animal Frontiers. 2023 Apr 1;13(2):28-34

[7] Leroy F, Beal T, Gregorini P, McAuliffe GA, van Vliet S. Nutritionism in a food policy context: the case of 'animal protein'. Animal Production Science. 2022 Feb 21;62(8):712-20.

[8] Salter AM. Improving the sustainability of global meat and milk production. Proceedings of the Nutrition Society. 2017 Feb;76(1):22-7.

[9] Jackson RB, Saunois M, Bousquet P, Canadell JG, Poulter B, Stavert AR, Bergamaschi P, Niwa Y, Segers A, Tsuruta A. Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources. Environmental Research Letters. 2020 Jul 15;15(7):071002.

[10] Saunois M, Jackson RB, Bousquet P, Poulter B, Canadell JG. The growing role of methane in anthropogenic climate change. Environmental Research Letters. 2016 Dec 12;11(12):120207.

[11] Steinfeld H, Opio C, Chara J, Davis KF, Tomlin P, Gunter S. Overview paper: Livestock, Climate and Natural Resource Use. https://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2019_Sept_Kansas/4_Climate_and_Natural_Resource_Use_-_Online_consultation.pdf

[12] Rojas-Downing MM, Nejadhashemi AP, Harrigan T, Woznicki SA. Climate change and livestock: Impacts, adaptation, and mitigation. Climate risk management. 2017 Jan 1;16:145-63.

[13] IFAD (International Fund for Agricultural Development) https://www.ifad.org/documents/38714170/40864504/CAR_2018_web.pdf/c88b3b3b-92a4-4a48-9536-ded3c83fed87

[14] Brito LF, Bedere N, Douhard F, Oliveira HR, Arnal M, Peñagaricano F, Schinckel AP, Baes CF, Miglior F. Genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. Animal. 2021 Dec 1;15:100292.

[15] FAO. Animal Genetics. http://www.fao.org/animal-genetics/background/why-is-ag-important/en/ [accessed November 2023].

[16] Cammack KM, Austin KJ, Lamberson WR, Conant GC, Cunningham HC. Ruminant nutrition symposium: Tiny but mighty: The role of the rumen microbes in livestock production. Journal of animal science. 2018 Feb;96(2):752-70.

[17] Johnson KA, Johnson DE. Methane emissions from cattle. Journal of animal science. 1995 Aug 1;73(8):2483-92.

[18] Arndt C, Hristov AN, Price WJ, McClelland SC, Pelaez AM, Cueva SF, Oh J, Dijkstra J, Bannink A, Bayat AR, Crompton LA. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 C target by 2030 but not 2050. Proceedings of the National Academy of Sciences. 2022 May 17;119(20):e2111294119.

[19] Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, Waghorn G, Makkar HP, Adesogan AT, Yang W, Lee C, Gerber PJ. Special topics—Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. Journal of animal science. 2013 Nov 1;91(11):5045-69.

[20] Veneman JB, Saetnan ER, Clare AJ, Newbold CJ. MitiGate; an online meta-analysis database for quantification of mitigation strategies for enteric methane emissions. Science of the Total Environment. 2016 Dec 1;572:1166-74.

[21] Tseten T, Sanjorjo RA, Kwon M, Kim SW. Strategies to mitigate enteric methane emissions from ruminant animals. J. Microbiol. Biotechnol. 2022 32(3):269-277.

[22] Chiariotti A. Rumen environmental and nutritional strategies to mitigate emissions from livestock. Cuban Journal of Agricultural Science. 2023 Oct 16;57.

[23] Tapio I, Snelling TJ, Strozzi F, Wallace RJ. The ruminal microbiome associated with methane emissions from ruminant livestock. Journal of animal science and biotechnology. 2017 Dec;8(1):1-1.

[24] Thornton PK, van de Steeg J, Notenbaert A, Herrero M. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agricultural systems. 2009 Jul 1;101(3):113-27.

[25] Cheng M, McCarl B, Fei C. Climate change and livestock production: a literature review. Atmosphere. 2022 Jan 15;13(1):140.

[26] 26. Sabia E, Napolitano F, Claps S, De Rosa G, Barile VL, Braghieri A, et al. Environmental impact of dairy buffalo heifers kept on pasture or in confinement. Elsevier Agricultural System. 2018;159(c):42-49. https://doi.10.1016/j.agsy.2017.10.010.

[27] Grossi G, Goglio P, Vitali A, Williams AG. Livestock and climate change: impact of livestock on climate and mitigation strategies. Animal Frontiers. 2019 Jan;9(1):69-76.

[28] 28 Monteiro A, Santos S, Gonçalves P. Precision agriculture for crop and livestock farming—Brief review. Animals. 2021 Aug 9;11(8):2345.

[29] Tilman, D. and Clark, M., 2014. Global diets link environmental sustainability and human health. Nature, 515(7528), pp.518-522.

[30] Twine, R., 2021. Emissions from animal agriculture—16.5% is the new minimum figure. Sustainability, 13(11), p.6276.

[31] Hou D, Bolan NS, Tsang DC, Kirkham MB, O'Connor D. Sustainable soil use and management: An interdisciplinary and systematic approach. Science of the Total Environment. 2020 Aug 10;729:138961.

[32] Terramoccia S, Bartocci S, Taticchi A, Di Giovanni S, Pauselli M, Mourvaki E, Urbani S, Servili M. Use of dried stoned olive pomace in the feeding of lactating buffaloes: Effect on the quantity and quality of the milk produced. Asian-Australasian journal of animal sciences. 2013 Jul;26(7):971.

[33] Tong F, Wang T, Gao NL, Liu Z, Cui K, Duan Y, Wu S, Luo Y, Li Z, Yang C, Xu Y. The microbiome of the buffalo digestive tract. Nature Communications. 2022 Feb 10;13(1):823.

[34] Contò M, Cifuni GF, Iacurto M, Failla S. Effect of pasture and intensive feeding systems on the carcass and meat quality of buffalo. Animal Bioscience. 2022 Jan;35(1):105.

[35] Abd El-Salam MH, El-Shibiny S. A comprehensive review on the composition and properties of buffalo milk. Dairy science & technology. 2011 Nov;91:663-99.

[36] de Oliveira LS, Alves JS, Bastos MS, da Cruz VA, Pinto LF, Tonhati H, Costa RB, de Camargo GM. Water buffaloes (Bubalus bubalis) only have A2A2 genotype for beta-casein. Tropical Animal Health and Production. 2021 Mar;53:1-4.