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Invited Review

Components of sustainable animal production and the use of silvopastoral systems

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ABSTRACT - There is an urgent need for sustainable animal production systems. A system or procedure is sustainable if it is acceptable now and if its expected future effects are acceptable, in particular in relation to resource availability, consequences of functioning, and morality of action. What might make any animal usage system unsustainable? The system might involve depletion of resources such that a resource becomes unavailable or a product of the system might accumulate to a degree that prevents the functioning of the system. However, any effect which the general public find unacceptable makes a system unsustainable. A production system might be unsustainable because of inefficient usage of world food resources; adverse effects on human health; poor animal welfare; harmful environmental effects, such as low biodiversity or insufficient conservation; unacceptable genetic modification; not being "fair trade", in that producers in poor countries are not properly rewarded; or damage to rural communities. Consumers might judge, because of any of these inadequacies, that the quality of the product is poor. Animal welfare is a component of sustainability and good quality of product. Three-level plant production, including pasture, shrubs with edible leaves, and trees that may also have edible leaves, are an example of a silvopastoral system. The production of leaves and other material that can be eaten by the animals is much greater than can be achieved by pasture-only systems. Results presented from tropical and sub-tropical studies show that production of cattle and other animals can be better, biodiversity much increased, animal disease reduced, and animal welfare improved in three-level silvopastoral systems.

Key Words: animal welfare, disease control, livestock, silvopastoral, sustainability

Changing ideas about sustainability

The meaning of the term sustainable is now much wider than it was in the past. Systems were initially called unsustainable when a resource became depleted so much that it became unavailable to the system, or when a product of the system accumulated to a degree that prevented the functioning of the system. Now, the meaning of the term is much wider; for example, a system can be unsustainable because of negative impacts on human health, animal welfare, or the environment. A definition of sustainability is: a system or procedure is sustainable if it is acceptable now and if its expected future effects are acceptable, in particular 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 of industrial and livestock production practices. Consumers 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, described briefly below.

What might make an animal usage system unsustainable? A consequence of the definition above is that any effect which the general public find unacceptable makes a system unsustainable. Members of the public in all parts of the world, particularly in developed countries, are now insisting on transparency in commercial and governmental activities and on changes in methods of producing various products (Broom, 2017). A production system might be unsustainable because of: inefficient usage of world food resources; adverse effects on human health; poor animal welfare; harmful environmental effects, such as low biodiversity or insufficient conservation; unacceptable genetic modification; not being "fair trade", in that producers in poor countries are not properly rewarded; or damage to rural communities. Any of these inadequacies could result in the quality of the product being judged

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as poor. In the future, consumers are likely to demand that sustainable systems are used. If they are not, retail companies, production companies, and countries that do not produce good quality, sustainable products are likely to be boycotted and, hence, forced to change (Bennett et al., 2002, Broom, 2014).

The following subsections briefly describe components of unsustainable systems that are also factors leading to animal products being regarded as of poor quality. The section headed "Sustainable systems and welfare" summarises data on sustainability concerning some silvopastoral systems.

Efficient use of world resources

At present, some food for humans and for farmed animals is wasted. Much food that humans could eat is given to animals that will be eaten by people, a much less efficient process than for the humans to eat the food directly. What can be done in animal production to exploit existing resources better (Herrero et al., 2010)? The most important animals for food production are those that eat food that humans cannot eat. Hence, herbivores eating forage plants, not cereals, are much more important than pigs or poultry, which compete with humans for food (Broom et al., 2013). Similarly, herbivorous fish are more important than those fish that eat other fish.

Land used for agriculture is sometimes not exploited efficiently and too much energy from fossil fuels is used in cultivation and transport of feed and products. Maintaining resources, such as soil with good structure, and retaining water that might be lost from the soil are important objectives, as is minimising usage of carbon-based energy and imported fertilisers. Soil is often damaged by tillage and greenhouse gases emitted (Pagliai et al., 2004).

Adverse effects on human health

Some foods are regarded as being better for the health of the consumers because of the nutrients present in them. A major effect of attempts to provide a healthy diet on animal production in recent years has been the dramatic increase in the production of farmed fish, in part because they contain poly-unsaturated fats (Wall et al., 2010). As open-water fish management has failed in most parts of the world, fish-farming has increased and is likely to increase further. In the future, it is suggested for resource-usage reasons that herbivorous fish are likely to be the most important species and the welfare of fish and impact of farms on the environment will have to be fully considered for there to be public acceptance of the products.

In all aspects of farming, antibiotic use will have to decrease in most countries via legislation. This is because of the development of antibiotic resistance, largely because of misuse of antibiotics in human medicine, but partly because of widespread rather than just therapeutic use in livestock farming (Ungemach et al., 2006).

Negative impacts on animal welfare

Poor animal welfare is probably the third most important reason for unsustainable livestock production. Welfare is the state of the individual as regards its attempts to cope with its environment (Broom, 1986), so it can be measured scientifically. Measures of animal disease are often important, because health is a key part of welfare. Other measures, for example of behaviour, physiology, immune system function, and body damage, are described by Broom (2014) and Broom and Fraser (2015). Close confinement of animals, individual rearing of social animals such as pigs and cattle, and other systems for housing and managing animals that do not meet the needs of the animals are so much disliked by many consumers that they will not buy the animal products. Hence, some widely-used animal housing systems are unsustainable (Broom, 2017). The welfare of animals kept on pasture-only systems can be poor because of heat-stress, parasitic and other infectious disease, and low nutrient availability with associated competition (Petherick, 2005). The welfare of animals in feedlots is often worse than that of animals on pasture.

Harmful environmental effects

Agricultural methods that result in low biodiversity and the need for conservation are a consequence of widespread herbicide and pesticide use and perceived to be the norm by many farmers and some of the general public. However, biodiversity on farmland can be much increased in some systems. Livestock production can also result in pollution, locally and on a world-wide scale, e.g., via greenhouse gas production. Greenhouse gas production should be reduced and may have to be balanced against efficiency of use of world resources (Broom et al., 2013).

Unacceptable genetic modification

Many people in the world are unwilling to accept the use of genetically modified plants and few people accept the use of genetically modified or cloned animals. One reason for this is dislike of modifying what is natural. Another is that modified organisms may have allergenic proteins and

many of the public do not believe that proper checks on such possibilities are in place. Genetically modified animals may be more likely to have welfare problems so there should be checks using a wide range of welfare indicators before they are used for any purpose (Broom, 2008, 2014).

Not being "fair trade"

In recent years, consumers in many countries have been appalled to find that food producers in poor countries are often not properly rewarded for their work. Most profits from the sale of some basic products bought by many people are found to go to large companies. As a consequence of publicity about unfairness to poor producers, products like coffee, cocoa, and fruit are among those that are independently checked and have a Fair Trade label (Nicholls and Opal, 2005). Hence, the producers receive a larger part of the money paid by shoppers in relatively rich countries.

Damage to rural communities

When small-scale rural farmers are out-competed by large-scale production, local communities may disappear. The general public often find this unacceptable; so, schemes are introduced by governments to safeguard such communities. Consumers may also buy locally produced products, regarding this as a part of product quality. In the European Union, subsidies to preserve rural communities have prevented large cities from increasing in size (Gray, 2000; Broom, 2010).

Sustainable systems and welfare

Livestock in woodland

Agroforestry allows the use of spaces or clearings in woodland for livestock. The animal production is additional to woodland production and may have benefits when dung components are utilised by the plants (Mcadam et al., 2007). Animal welfare and other aspects of sustainability are better than the average in animal production, for example, when Andalucian or Portuguese pigs exploit woodland (Castro, 2009). The trees may be chestnut or oak (Table 2) and the pigs eat the fruits of the trees, either when these are produced or later. Agroforestry produces wood, as well as meat or other animal products (Tirapicos Nunes, 2007; Santos Silva and Tirapicos Nunes, 2013), and often provides an environment that results in good welfare for the animals.

The woodland may itself be made up of trees planted for production of a human resource. For example, in Malaysia cattle can utilise areas between trees in oil-palm plantations. Agropastoral combinations of soya or other crops and cattle can have various benefits. However, we have little knowledge of the effects on animal welfare.

Silvopastoral three level systems

Three-level plant production, including pasture, shrubs with edible leaves, and trees that may also have edible leaves, are an example of a silvopastoral system. A cattle production system whose characteristics and objectives include using three-level or other multi-level production of edible plants; managing the soil, taking account of worms and water retention; encouraging predators of harmful animals; minimising greenhouse gas emissions; improving job-satisfaction for stock-people; reducing injury and stress in animals and maximising good welfare; considering how to encourage biodiversity using native shrubs and trees; and utilising the potential for obtaining wood from trees is explained by Murgueitio et al. (2008, 2011), Giraldo et al. (2011), Naranjo et al. (2012), and Broom et al. (2013). Some of the species used as food for livestock in tropical and temperate silvopastoral systems are listed in Table 1 and Table 2. Some of the trees are used as "live fences" (Nahed-Toral et al., 2013; Villanueva-López et al., 2014).

Table 1 - Tropical and sub-tropical shrubs and trees that are eaten by sheep, goats, and cattle in South America

Species	Common name(s)
Gliricidia sepium	quickstick, mata ratón
Guazuma ulmifolia	bay cedar, guácimo
Morus alba	white mulberry, morera
Leucaena leucocephala	leucaena
Brosimum alicastrum	Maya nut, ramón
Tithonia diversifolia	tree marigold, botón de oro
Trichanthera gigantea	tricanthera, nacedero
Erythrina edulis E. poeppigiana	poroto, búcaro
Boehmeria nivea	ramie, ramio
Cratylia argentea	veranera
Malvaviscus penduliflorus	mazapan

Table 2 - Shrubs and trees that are used as forage for ruminants and pigs in temperate countries

Species	Common name(s)
Castanea sativa	sweet chestnut
Castanea mollissima	Chinese chestnut
Quercus pyrenaica	Pyrenean oak
Quercus ilex	evergreen oak
Quercus suber	cork oak
Olea europea	olive
Alnus nepalensis	Nepalese alder
Sesbania sesban	sesban
Chamaecytisus prolifer	tagasaste
Robinia pseudoacacia	black locust/frisia
Sambucus canadiensis	American elder
Helianthus tuberosum	Jerusalem artichoke (herb)

There are also possibilities for feeding tree and shrub leaves to pigs, poultry, or farmed fish. Where shrubs and trees are too high for animals to reach, branches can be cut and offered to the animals.

The production of leaves and other materials that can be eaten by the animals is much greater in silvopastoral systems than in pasture-only systems. Results from tropical and sub-tropical studies show that cattle production can be better. Three-level forage production produces more usable plant material than pasture only. Pasture plus *Leucaena* produced 29% more mass and 64% more protein than monoculture herbage-layer only systems. Nitrogen-fixing plants are used; so, less artificial fertiliser is needed. Animal production yields can be greater on silvopastoral systems than on semi-intensive silvopastoral systems than on monoculture systems (Table 3) (Murgueitio et al., 2011). Three-level silvopastoral systems generally have better soil structure, better water retention, and less soil loss (Murgueitio et al., 2008; Broom et al., 2013).

Three-level silvopastoral systems have much greater biodiversity than monoculture, single-level systems. The number of bird species increased by 200%, that of ants by 30%, and there were also increases in the numbers of butterflies. There was less pollution run-off because of water-holding properties of soil, 30% less methane production per kg meat, and better carbon sequestration. Workers on silvopastoral farms reported better job satisfaction (Broom et al., 2013).

The animal welfare in silvopastoral systems has been demonstrated to be better in various ways than that on pasture-only systems (Table 4) (Broom, 2015; 2016). The beneficial effects of shade are substantial in hot weather with cattle skin temperatures up to 4 °C lower than in pasture-only systems. High temperature increases water and energy loss and reduces foraging times in paddocks fully exposed to the sun (Améndola, 2013; Améndola et al., 2016). Less sun exposure results in less sun-burn, less cancer, and less photosensitisation (Rowe, 1989).

Anxiety and fear, including fear of humans, can be reduced when partial concealment is possible. This leads to better human-animal interactions and easier handling (Ocampo et al., 2011; Mancera and Galindo, 2011). More choice of food in silvopastoral systems results in more control by each individual animal of its environment and thus social behaviour is more normal (Améndola et al., 2016).

The increase in predators lowers the populations of ticks and injurious insects, such as horn flies, and hence reduces the incidence of diseases such as anaplasmosis, which has been shown to drop from 25 to <5% (Murgueitio and Giraldo, 2009). Reduction in diseases also leads to reduced antibiotic use. The presence of nitrogen-fixing shrubs, such as *Leucaena*, improves animal nutrition and this, together with the better water-retention by the soil, reduces the likelihood of thirst and starvation. Feeding behaviour is improved at high temperature and humidity if the animals are in a silvopastoral system (Ceballos et al., 2011). It may be that the improvement in dietary choice contributes to this beneficial effect (Manteca et al., 2008).

A study of welfare in three intensive silvopastoral systems was carried out in Colombia with *Leucaena*

Table 3 - Summary of comparisons between monoculture and semi-intensive silvopastoral systems

	"Improved" monoculture pasture	Semi-intensive silvopastoral system
Metabolisable energy (Mcal.ha^{-1})	56.9	70.2
Crude plant protein (tonne ha^{-1})	2.5	4.1
Milk per cow (kg day^{-1})	3.5	4.1
Meat (kg ha^{-1} year^{-1})	183	821
Methane (tonne of meat^{-1})	208	128
Bird species	24	75
Anaplasmosis (% of herd)	25	<5
Fights (% difference)	+37	
Social licking (% difference)		+65
Social interactions in shade (% difference)		+57

Re-analysed data from Murgueitio et al. (2008), Broom et al. (2013) and Améndola et al. (2013, 2016).

Table 4 - Summary of benefits of silvopastoral systems for animal welfare

Nutritional improvement because of shrub and tree intake	Murgueitio et al., 2011
Thermal comfort resulting from more shade	Mancera and Galindo, 2011
Less fear because of concealment	Ocampo et al., 2011
Better health because of more predators of ticks and flies	Murgueitio and Giraldo, 2009
Better body condition because of nutrients, shade, and less disease	Ocampo et al., 2011; Tarazona Morales et al., 2017
Improved food intake and social behaviour	Améndola, 2013; Améndola et al., 2013, 2016
Better human-animal interactions	Mancera and Galindo, 2011

leucocephala and *Guazuma ulmifolia* as shrubs for browsing at more than 8,000 shrubs/ha and several tree species (Tarazona Morales et al., 2017). The needs of the cattle were met, there being good food and water availability, effective body temperature control and physical comfort, good social behaviour, and low parasite levels. Some respiratory infection occurred on one farm, but this might be expected by chance.

When the social behaviour of cattle was compared in a silvopastoral system and a pasture-only monoculture system in the region of Merida, Yucatán, Mexico, there was more affiliative social behaviour in the silvopastoral system (Améndola, 2013; Améndola et al., 2013, 2016). Social licking was the main affiliative behaviour and was shown by 78% of the heifers in the silvopastoral system, but only 47% in the monoculture system. In the silvopastoral system, 57% of interactions occurred in the shade. Head-butting and chasing occurred in the silvopastoral system, but often did not develop into a fight. Social licking is known to occur after the animals have obtained food and shelter (Sato et al., 1991), but it does reduce the heart rate of the participants (Laister et al., 2011) and contributes to the stability of social relationships in cattle (Sato et al., 1993).

Conclusions

In relation to animal production throughout the world, there will be increasing demand from consumers for more efficient use of world resources and the avoidance of adverse effects on human welfare, animal welfare, and the environment.

Industry has to rapidly change policies relating to animal welfare and other aspects of sustainability. The animal production industry should be proactive.

Tropical and temperate livestock production should consider three-level silvopastoral systems, with shrubs and trees with edible leaves.

Animal welfare has been developing rapidly as a scientific discipline and the benefits of silvopastoral systems for animal welfare have been studied.

The animal welfare benefits of three-level silvopastoral systems include nutritional improvement because of shrub and tree intake; thermal comfort resulting from more shade; less fear because of concealment; better health because of more predators of ticks and flies; less risk of cancers and other diseases caused by too much direct sunlight; better body condition because of nutrients, shade, and less disease; improved food choice, food intake, and social behaviour; and better human-animal interactions.

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