The Journal of Agricultural Science

cambridge.org/ags

Editorial

Cite this article: Charles D (2019). Guest Editorial: Sustainable agricultural systems and farm animals: the historical and biological evidence. *The Journal of Agricultural Science* **157**, 563–565. https://doi.org/10.1017/S0021859620000209

Author for correspondence:
David Charles,
E-mail: dandscharles@hotmail.co.uk

Guest Editorial: Sustainable agricultural systems and farm animals: the historical and biological evidence

David Charles

The acquisition of food as an application of biological knowledge could be said to have begun with the hunter gatherers of the Middle Pleistocene epoch, about 7 00 000 years ago (Tannahill, 1988; Larsen, 2000; Charles, 2002), and therefore to have predated agriculture. The adult male hominids hunted large and small game animals, while the females gathered plant material such as fruits and seeds. The males needed to know the habits and vulnerabilities of their quarry, since hunting with primitive weapons was dangerous. Confronting a cornered enraged adult aurochs (*Bos primigenius*), for example, must have been a daunting experience. The females were the gatherers, and they must have learned the hard way which plant foods were safe to eat and which were poisonous (Nicholson *et al.*, 1980). The anatomical accuracy of prehistoric cave paintings of animals suggests acute and detailed observation.

Agriculture began to emerge in the Neolithic period. The annual migration from lowland caves in winter to upland pastures in summer probably taught early man that plants sprang from seeds, perhaps from the previous year's rubbish heaps (Tannahill, 1988; Charles, 2002). The next step was to plant the seeds on purpose. The cereal einkorn wheat (*Triticum monococcum*; Diamond, 1997; Heun *et al.*, 1997), identified by DNA fingerprinting, may have been one of the first cultivated crops, about 11 000 years ago. It also occurred to Neolithic peoples that it might be easier to tame, enclose and control prey animals rather than to hunt them. The first animal domestication may have been the sheep (*Ovis aries*) about 11 000 years ago (Ryder, 1984), followed by the pig (*Sus scrofa*) about 9000 years ago (Epstein and Bichard, 1984), the goat (*Capra hircus*) also around 9000 years ago (Mason, 1984), cattle (*Bos taurus*) about 8000 years ago (Epstein and Mason, 1984) and the chicken (*Gallus domesticus*) about 8000 years ago (West and Zhou, 1989). Early man must have realized that the ruminant animals (mammalian order *Artiodactyla*) were effectively increasing the range of plant species available for human food, particularly in terrain where grasses (botanical family *Poaceae*) grew well, but where other plants did not. But they could not have known that this attribute of the *Artiodactyla* was due to microbial fermentation in the rumen breaking down structural carbohydrates and permitting the digestion of cellulose, as well as the synthesis of amino acids and vitamins (Ewing and Cole, 1994). Their butchery activities would have made them aware of the size and complexity of the ruminant digestive system, but not of its microbiology.

The domestication of crop and animal species meant that migrating hunter-gatherers could become settled farmers, and it also meant that no longer did everyone have to function as a food provider. Consequently, division of labour eventually made ancient civilizations possible and the process has sometimes been aptly called the Neolithic revolution. At first, the great civilizations of the ancient world realized that they depended on the husbandry of their soil, their crops and their animals. Their writings make this clear. In the 8th century BC, the Greek poet Hesiod wrote at length on farming advice to the young, advocating some things which we would still regard as sound practice (Charles, 2002). Another Greek, Theophrastus in the 3rd century BC, knew that beans (family *Fabaceae*) invigorated the soil (Shorrocks, 2017). The Roman authors Cato, Virgil and Varro, though better known for other things, all wrote on farming practice (Shorrocks, 2017); however, perhaps the most influential Roman agricultural author was Columella in the 1st century AD, who wrote a collection of 13 books on husbandry, translated from Latin into English in 1745. He seems to have been aware that there were some underlying biological principles, and he advocated manuring and the application of dung from livestock (Columella, tr. 1745; Shorrocks, 2017). In the 4th century, Palladius wrote 14 books on husbandry, translated into English in 1873 (Lodge, 1873).

Later, however, the ancient civilizations seem to have forgotten about the care of their land and it has even been suggested that one of the reasons for the fall of the Roman empire was the abuse of its soil (Montgomery, 2017). Using this as a lesson from history, the same author expressed concern about the present day continuing global losses of soil from ploughed fields, which he estimated at just over 1 mm per year, or about a hundred times the rate of soil production. He suggested updating the centuries-old practice of integrating crop and livestock production, giving the opportunity to turn animal manure into a tool for building soil health. The value of livestock in producing manure to promote soil fertility and crop growth in 19th century England was discussed by Wiseman, who produced clear evidence that the profitability of rearing animals was often based only on the value of the manure they produced (Wiseman, 1986). Currently, the British farming press frequently covers practical examples of such soil care through mixed farming. The ancient Egyptians did not usually need to worry about the care of their soil because the flooding of the Nile renewed it by depositing silt from further upstream (Charles, 2002).

In Britain, for over 1000 years after the Romans left the sustainability of soil fertility and soil structure was achieved mainly by fallowing every 2–4 years, depending on the location, in unfenced open field villages. But this was too wasteful once the industrial revolution resulted in larger urban populations to be fed. The open three-field system survives at Laxton, Nottinghamshire (UK), where 711 ha in the parish was purchased in 1951 by the Ministry of Agriculture to preserve the heritage for the nation (Rundle, 1955).

After enclosure of the fields and the creation of individual farms, crop rotations became more systematic. A classic four-course crop rotation was practised in the 18th century by Viscount Charles Townsend (1674–1738). Although his day job was Foreign Secretary at a time of turbulent European politics, he is known to history as Turnip Townsend, because on his Raynham Estate in the UK, the famous Norfolk four-course rotation was wheat–turnips–barley–clover (Wade Martins, 1990). Sheep ate the turnips and clover, and the clover restored soil fertility, though Townsend would not have known that clover's restorative value was due to nitrogen-fixing bacteria (Parsons, 2017). White clover (*Trifolium repens*), for example, can fix 100–200 kg N/ha per year (Shorrocks, 2017). Ruminants utilizing clover or other nitrogen fixers can therefore have an environmentally beneficial fertilizer sparing effect.

Another 18th century Norfolk estate owner, Thomas Coke (pronounced Cook; 1754–1842) of Holkham, organized training events for his tenant farmers, called the Holkham Sheep Shearings, where crop rotations, animal husbandry and the care of the soil were discussed (Charles, 2002). At around the time of this interest in crop rotations and care of the soil in East Anglia (UK), Erasmus Darwin (1731–1802) in the Midlands was writing on *The Economy of Vegetation* and a *Philosophy of Agriculture and Gardening* (Priestland, 1990). He was the grandfather of Charles Darwin.

Next came the age of the agricultural sciences. In a short article, it is impossible to do justice to the work of hundreds of people and numerous institutes and centres, but perhaps some highlights whose histories have been famously published could be mentioned as examples. Scott Watson and Hobbs (1937) described the work of practical husbandry pioneers, mostly in the 19th century. Sir John Russell documented the agricultural sciences from the 17th to the 20th centuries (Russell, 1966). His own institute at Rothamsted (UK) put many key aspects of crop, animal, and soil husbandry onto a systematic and scientific basis. In particular, the concepts of randomization and replication in field experiments were developed, in order to allow for chance effects and biological variation. At Rothamsted, Sir Ronald Fisher and Frank Yates pioneered much of the branch of mathematics now called statistics, used in the analysis of such variation (Fisher and Yates, 1963). This became a standard procedure underpinning many agricultural and other biological sciences, and later in industrial quality control. Many agricultural disciplines have their own documented histories, summarized elsewhere (Charles, 2002).

In the 20th century, a range of organizations, both public and private, ran research and advisory services (Charles, 2002). Much of this amounted to comprehensive applied agricultural science at a wide range of levels applied on thousands of British farms, aimed at securing post-war food supplies, food rationing having been necessary during both world wars and not ending after World War II until 1954.

Mid-20th century concerns about national food security included utilization and sustainability of the hills and uplands. In a study first published in 1935, and running to three editions and seven impressions until 1949, Sir George Stapledon wrote an influential analysis of the contribution of the hills to national life, leisure, ecology and food supply (Stapledon, 1944). He outlined what National Parks might become, and they were established as we now know them in 1951. Grazing farm animals were then, and still are, part of their essential fabric, through the effects of their grazing on the preservation of habitats. For example, their trampling helps to control bracken (*Pteridium aquilinum*), which would otherwise dominate and reduce biodiversity. Livestock therefore help to maintain the familiar characteristic appearance of the grassy hills of many important British tourist areas. In 2016, there were 5.16 million ha of rough grazing land in the UK (Redman, 2017), so it is not a trivial resource.

A brief digression on the economic contributions of farm livestock may be appropriate at this point, since an important part of Stapledon's concept of National Parks was that people live and work in them. The contributions of livestock sectors to local economies have sometimes been found to be more far-reaching than expected. In a study of 15 livestock and related industries in the West Midlands (UK) in 1995, using matrix manipulation and the Leontief inverse technique, an increase or decrease of £1 million in the supply of output to consumers created or lost 58 jobs, 79.9% of which were outside the sector (Unwin and Parsons, 1995).

Contemporary debates often overlook the contribution of animal products to the human diet. A review of the contribution is beyond the scope of this article, but detailed tables of the composition of several hundred foods and food products, of animal and plant origin, have been published regularly for many years (Food Standards Agency, 2002). The importance of these tables is illustrated by the history of their publication. The first edition by Robert McCance and Elsie Widdowson was compiled in 1940, because during World War II it was important to supply Britain with a balanced diet based on home production and limited resources. Many editions followed, compiled by teams of contributors. Yet despite such information, and a long and distinguished history of the scientific basis of human nutrition (Garrow *et al.*, 2000), we are now frequently confronted by media coverage of dietary recommendations, often expressly dismissive of animal products, promoted by celebrities from the world of the arts or of journalism, and not that of the biological, nutritional or agricultural sciences.

The World War II war effort saw the publication in 1940 of Sir John Hammond's book on the genetics and physiology of farm animals, which ran to its 3rd edition in 1960 (Hammond, 1960). The systematic breeding of superior genotypes of grasses for livestock feeding had already been taking place since 1919 at the Welsh Plant Breeding Station at Aberystwyth (UK), under Sir George Stapledon as its first director.

Has the application of centuries of science and technology had much practical effect on the yields of crops and animals, and therefore on the supply and affordability of food? Data have been compiled by Shorrocks for wheat yields in England through time, by 22 intervals (Shorrocks, 2017). Yields increased from 0.5 t/ha in 1200 AD to 8.6 t/ha in 2014; 80% of the increase was in the 20th century. He attributed the increase to factors including improved varieties, fungicides and better use of fertilizers (Shorrocks, 2017). From 1989 to 1999, milk yield of cows in the UK increased by 1.9% per year; and from 1990 to 1999, piglets reared per sow increased by 0.5% per year (Charles, 2002). From 1898 to 1999, eggs per hen per year increased from 149 to 300 (Charles, 2002). At least partly as a result of all this improved productivity, the proportion of the average worker's total expenditure spent on food fell from 60% in 1901 to 10% in 1999 (Charles, 2002), despite the fact that the price of modern foods often includes cleaning, packaging and even some preparation.

After such an august scientific heritage, it would be sad if in the 21st century we should regress to single-issue biology such as the current focus on the methane output of ruminants, ignoring their other biological and ecological effects. Neither sustainable agricultural systems nor agricultural sciences are as simple as that. Surely it would be regrettable if we discard the lessons of history and of applied sciences in favour of selective evidence supporting fashionable mores. The methane output of ruminants is an egregious example. The fact that they produce methane has become common knowledge, but their place in sustainable rotations, and in fossil fuel sparing by utilizing N-fixing legumes, have not.

Methane outputs of farm animals and man (adapted from Blaxter, 1989)

Species and feeding regime	Methane output, kJ/100 kJ food
Sheep, barley straw	6.7
Sheep, barley grain	10.6
Cattle, 40% hay 60% grain	6.2
Horse, hay and oats	1.9
Horse, wheat straw	3.2
Pig, kale	0.4
Man, 42% fat, 18% protein	0.4

Values were not quoted for grazing sheep and cattle eating only grass, but they were suggested to be approximately proportional to the digestibility of the feed. A function for prediction was quoted. The table suggests that the values are not constant within species, but are affected by nutrition, so that there is scope for research on factors affecting the methane output of both farm animals and man. Interestingly, the value for man is not zero.

About the Author. Dr David Charles has spent most of his working life in agricultural research and consultancy, firstly with the National Agricultural Advisory Service (UK), which later became ADAS, and then self-employed. For many years, he was a Special Lecturer at the University of Nottingham (UK), Sutton Bonington Campus. An abiding interest in agricultural history included the publication of a book on the subject in 2002 by Nottingham University Press. In recent years, he has become increasingly concerned that some fashionable views about farm livestock ignore, or even deny, the historic and scientific evidence on their contributions to sustainability.

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