Forage Production and Utilisation: Forage Production for Improved On-Farm Wealth and Wellness

John Caradus
Grasslanz Technology Limited, New Zealand

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John Caradus

Grasslanz Technology Ltd, PB 11008, Palmerston North, New Zealand

Introduction

It is often overlooked that the world's largest agricultural land use by far is grassland, where these are mostly grazed by livestock, either domesticated or wild animals. Native grasslands are referred to as savanna (in Africa), steppe (in sub- Artic Eurasia), prairie (in North America), or pampas (in South America). Grasslands contribute to the livelihoods of more than 800 million people (FAO 2000). Native grasslands are maintained by restricted rainfall that reduces the opportunity for succession by forest. Grasslands are not only food for livestock, but also provide a habitat for wildlife, prevent soil erosion, support pollinators, and capture carbon which can then be sequestered into the soil through composting of leaf litter.

The world's grasslands and the way in which they are used can be categorised in a number of ways:

- Natural or native versus cultivated and sown
- Temperate versus sub-tropical versus tropical
- Arid through semi-arid
- Coastal plains to alpine meadows
- Grazed versus cut and carry
- Subsistence farming through corporate farms to factory farming

Grasslands of the world have been and are primarily used for conservation, recreation, and the production of animal protein production, primarily fibre, meat and milk. Depending on the definition of grassland it is estimated that between 20 and 40% of the earth's land area covered by grasslands (FAO 2006). That is about 4.1 to 5 billion ha (depending on definition), or about 70% of the global agricultural area (FAO 2000). The two largest producers of beef, USA and Brazil have 320 million ha and 200 million ha respectively of grazed grasslands.

Some of the world's most productive grassland systems are on land that was originally in forest (Figure 1 shows indigenous biomes and Figure 2 the change from native to modified grasslands). This change in vegetation cover includes much of western Europe, eastern USA, large areas of South America and smaller regions such as New Zealand and the eastern coastal area of Australia. Native forests once covered 80 per cent of New Zealand, but today they cover 26 per cent. In 2019, there was world-wide concern for the loss of forest in the Amazon sparked by disgruntled landlords or leasees seeking a change in land use which included an increase in grassland for grazing livestock. This dramatic large scale change in land use has sparked global concern.

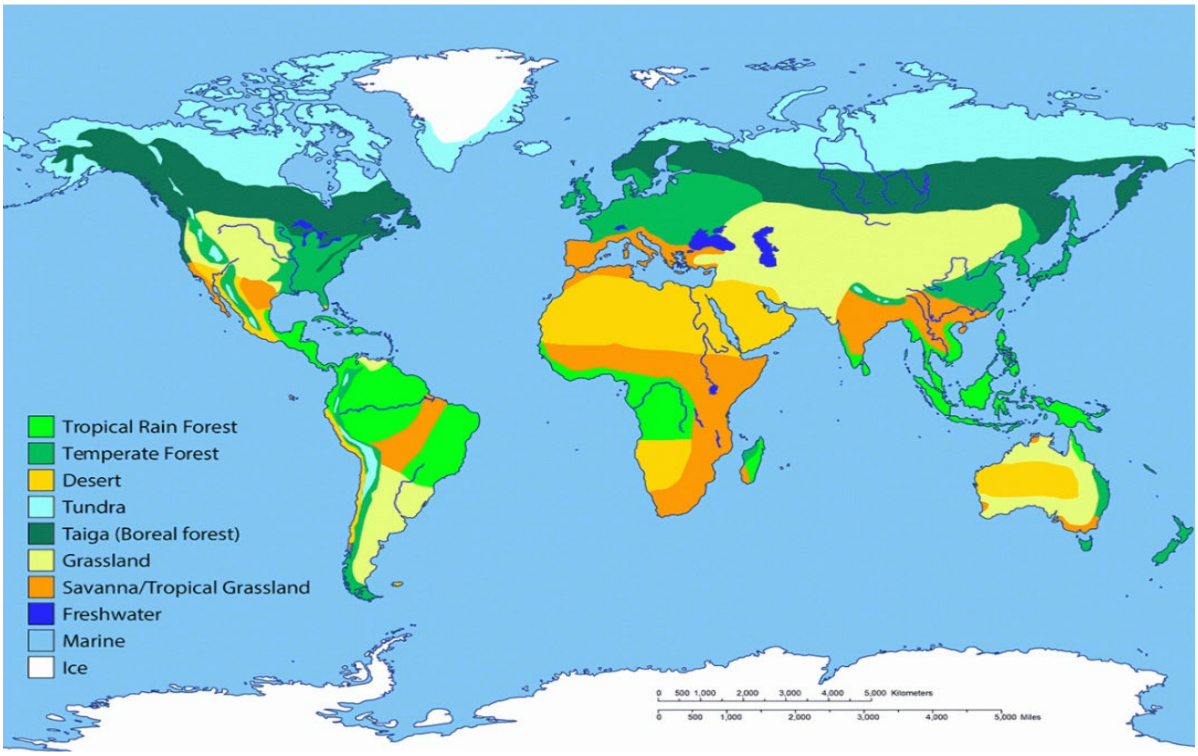

Figure 1 – Indigenous or original vegetative biomes (https://askabiologist.asu.edu/explore/biomes)

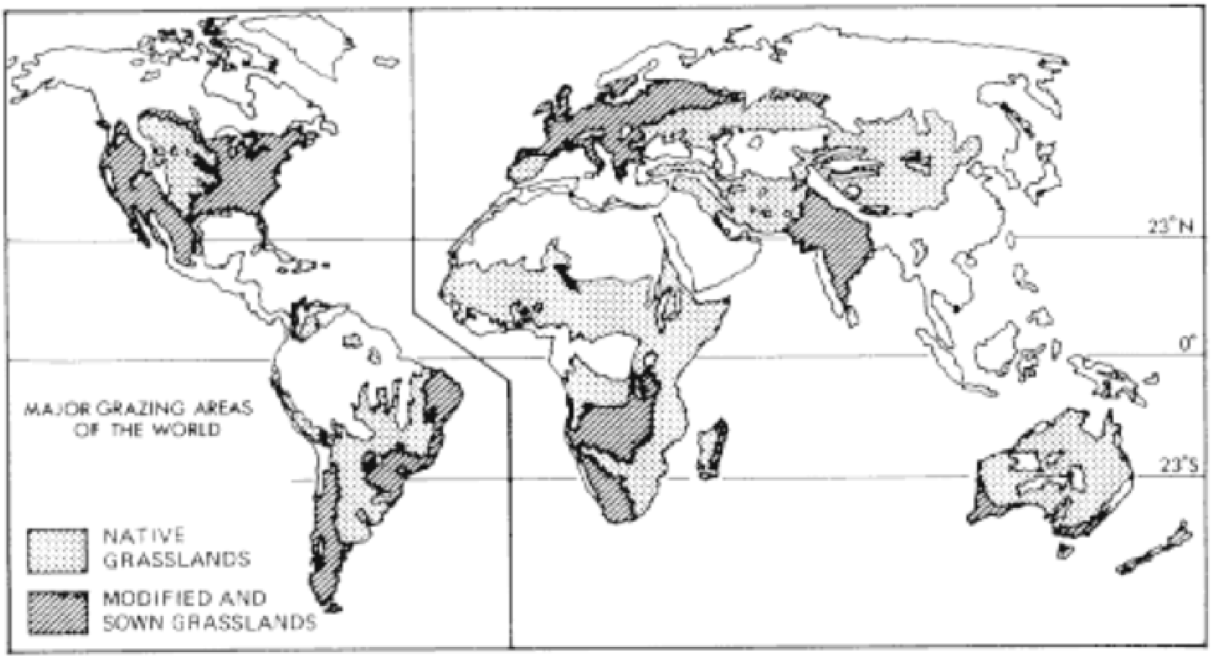

Figure 2 – Remaining native grasslands and modified and sown grasslands. (https://forages.oregonstate.edu/nfgc/eo/onlineforagecurriculum/instructormaterials/availabletopics/grasslands/definition)

While cultivated grasslands are of significance in supporting protein supply to a growing world population there is now a mounting debate on the environmental impact of grassland farming and whether it is a sustainable option (FAO 2006).

Threats to the continued use of grasslands

A review undertaken in 2018 (Sapere Research Group) identified 3 global mega trends likely to affect the future of food and farming:

1. Enhanced environmental consciousness - global consumers are increasingly demanding products that fulfil a growing range of environmental demands.
2. New technological developments and transformational science - these developments include advances in the science of genomics, plant-based proteins and cellular agriculture.
3. Changing consumer preferences – with an increased demand for quality, food safety, health benefits, provenance, ethics and biosecurity.

So what does this mean for the future of grassland and grassland farming? New Zealand's dairy herd has doubled in the last two decades to 6.5 million animals, nearly all of which graze forage outdoors year-round. But this trend has started to change with the challenges from artificial (non-animal) protein and operational constraints to minimise negative environmental impacts. An ambitious plan called the Global Deal for Nature has been proposed to prevent the world's ecosystems from unravelling which encourages countries to double their protected zones to 30 percent of the earth's land area, and add 20 percent more as climate stabilization areas, for a total of 50 percent of all land kept in a natural state (https://www.nationalgeographic.com/environment/2019/04/science-study-outlines-30-percent-conservation-2030/).

One western world perspective is that pastoral agriculture is on the road to extinction and the biggest challenge to pastoral farming is the social license to continue to farm. This is largely associated with an increased demand for environmental integrity and animal welfare (Stafford et al. 2002). In many countries environmental integrity is focused on protecting waterways from leached nutrients, particularly nitrogen, and from reducing methane gas emissions from ruminants (Foote et al. 2015). New Zealand agriculture faces significant concerns in the form of changing consumer tastes and increasing regulatory compliance as health and environment factors are increasingly prioritised.

Other threats include:

- Artificial laboratory based and plant protein and the future of the grazing animal
- Social attitudes driven by the rural urban divide
- Urbanisation and encroachment of cities onto fertile farmland
- Research capability, resources and funding devoted to grassland research is diminishing
- Land degradation through nutrient depletion and erosion in natural and cultivated grasslands
- Impacts of changing climate and global pandemics

Pastoral agriculture and grassland productivity, like other parts of society and economies, has been significantly disrupted by the COVID19 pandemic. Both supply and demand have been affected, although as a result of lockdowns, closed borders, travel restrictions, and social distancing rules imposed in many countries the greater impact has been on demand. Logistical constraints and labour shortages have resulted in reduced access to conserved animal feed and slaughterhouse capacity, and led to the destruction or waste of perishable items that are unable to be stored (Nicola et al. 2020; Siche 2020). In many countries the closure of restaurants and street food outlets removed a key market for many producers and processors, resulting again in deceased demand and lower prices at the farmgate. Efforts were made to keep agriculture safely running as an essential business so that at least local markets could be reliably supplied with affordable food. However, food insecurity was inevitable in countries which also had to manage fragile economies, internal conflicts, extremes of weather, and locust plagues.

Social attitudes driving the rural urban divide may be more imagined than real. A recent survey of more than 1000 people found New Zealanders are almost five times more likely to hold a positive view of sheep and beef farming than a negative one (https://farmersweekly.co.nz/section/agribusiness/view/they-like-you). And they are more than twice as likely to hold a positive view of dairy farming than a negative one.

The best antidote to disruption in farming is to innovate and continue to have the capacity and capability to innovate. This is largely about mitigating the risks, and delivering agritech solutions for a prosperous future. So what is being and can be done?

- Use of alternative forages – e.g. plantain to mitigate nitrogen losses to waterways through reduced rumen ammonia production (Navarrete et al. 2017) and reduced urinary nitrogen content (Chen et al. 2017)
- Use of microbial endophytes to improve adaptation to biotic and abiotic stresses (Johnson and Caradus 2019)
- Attempts to increase species diversity in managed grasslands (Tilman et al. 2014)
- Systems for real time monitoring of waterways and catchments leading to improved management of environmental impacts (Hodges et al. 2018)
- Reducing stocking rates in vulnerable catchments but increasing the value for the animal products produced (Sharma 2019). Largely this relies on the use of manufacturing and production processes to provide a product where the consumer is willing to pay a premium over a similar but undifferentiated product. This can occur both on-farm and off-farm through cooperative business ventures, but does require a different set of skills to those required for production farming.
- Improved management of effluent systems such as the ClearTech system being trialled at the Lincoln University Dairy Farm, Canterbury, NZ (Cameron and Di 2019).
- Artificial intelligence has been predicted to have a significant impact on agriculture over the next decade, although its genesis occurred in the 1980s (McKinion and Lemmon 1985). This will include the increased use of apps, sensors for disease, pest, crop and environmental monitoring/forecasting, smart alerts, decision support systems, machine learning, drones and robotic systems and increased automation.

Forage production systems - variety, distribution and scale

In many regions, including east Africa, central Asia, central South America and parts of the Australian interior, there is extensive use of native grassland for animal grazing. In eastern Africa about 75 percent of land area is dominated by natural grasslands, often with a varying amount of woody vegetation, and have been grazed by livestock and game for millennia (Figure 3). Brachiaria species, which are native to eastern Africa, have been extensively sown in tropical regions, such as large parts of Brazil and northern Australia, but only recently viewed as an option for parts of Africa.

Figure 3 – Impala and zebra grazing on native grasslands in Kenya

Perennial ryegrass *(Lolium perenne)* a native grass of Europe is used extensively in temperate regions of the world because of its high nutritive value. In higher rainfall regions of Australia about six million ha and in New Zealand about ten million ha have been sown to perennial ryegrass. Tall fescue, a native of Europe and northern Africa, has been widely used in cultivated pastures in North America, eastern Australia and southern South America. Temperate grasses are often sown with legumes such as white clover, red clover or annual clovers in drier areas, because increasing legume content of grazed pasture leads to improved animal productivity (Harris et al. 1997; Dineen et al. 2018; McClearn et al. 2020). However, lucerne, or alfalfa, is the most widely used legume and is generally sown as a monoculture in cut and carry systems.

The demand for increased diversity in grassland landscapes – is this important?

Cultivated grasslands are often sown to a small number of species, in distinct contrast to native grasslands which are often a complex ecosystem of many species. Improved ecosystem functionality and stability is postulated to occur with increased biodiversity (Tilman et al. 2014). However, can species diversity add any economic value to grazed grasslands? While grassland diversity restoration management increases the resistance of carbon fluxes to drought, it also reduces agricultural yields, revealing a trade-off for land managers (Cole et al. 2019). Using data from the longest-running biodiversity experiment in the world, which is at Cedar Creek Ecosystem Science Reserve Binder et al. (2018) modelled the ecological production function which quantifies the relationship between ecological inputs and particular ecosystem outputs. They found that even a risk-neutral, profit-maximizing landowner would favour a highly, but not maximally, diverse mix of 11 species. The relationship between diversity and primary production has been assessed at 3 geographically diverse sites, and include California annual grasslands, and old fields in New York and grasslands in the Serengeti (McNaughton 1993). A negative relationship was observed between productivity and diversity in the annual grasslands of California and the old fields of New York, while there was no relationship between productivity and diversity was found in the Serengeti. Conversely, Tilman and Downing (1994) observed that the effect of perturbation on production was maximised in simple systems and minimised in the most diverse systems. So is the jurying still out on the importance of diversity due to a lack of consistency from known results?

The role of legumes and herbs in grassland

As mentioned above, legumes in mixed grass swards are known to increase sward nutritional quality resulting in increased animal production (Harris et al. 1997; McClearn et al. 2020). They showed that the presence of white clover was associated with both an increased feed intake and the higher nutritive value of the clover. Over the past 20 to 30 years the enthusiasm for introduced legumes in managed pastures has 'waxed and waned' largely due to the increased availability of cheap nitrogen fertiliser. For intensive systems this has provided an increase in grass production that is easily and quickly captured in animal production, particularly for dairy farmers. However, the increased public awareness of the unintended consequence of this practice leading to poor water quality has resulted in calls to reduce nitrogen inputs and return to using biologically fixed nitrogen through the inclusion of legumes in grazed pastures. While this may not automatically reduce the leakage of nitrogen in rivers and water ways it is considered 'more natural' and hence more acceptable.

Have we reached the limits of genetic gain through phenotypic selection and breeding?

Estimates of genetic gain for key traits (yield, quality and persistence) in forage species due to plant breeding has been considered to be up to about 6% per decade (Wilkins and Humphreys 2003), but can be variable (Table 1), with genetic gain higher in white clover than red clover and lucerne (Woodfield and Brummer 2001). For comparison genetic gain in grain yield potential of wheat have been estimated to be approximately 11% per decade (Graybosch and Peterson 2010).

Options for improving grassland and forage production

If one considers that the measured genetic gain through conventional phenotypic selection is either too low or not realised on farm then what other options are available to ensure future productivity within allowable and acceptable environmental constraints?

- Endophytes and microbial symbionts: In New Zealand, Australia and parts of USA the persistence of perennial temperate grasses is heavily reliant on the presence of an obligate mutualistic fungal endophyte (*Epichloë* species) (Caradus and Johnson 2019). This endophyte produces secondary metabolites that protect the plant from insect pests and provides improved tolerances to some abiotic stresses, such as drought. Other microbial options need to be explored and developed for other forages to improve adaptation and resistance to both biotic and abiotic stresses.

Table 1 – Estimates of genetic gain for yield due to breeding in a number of forage species.

Forage species	**Estimated genetic gain for yield per year (%)**	**Region**	**Reference**
Perennial ryegrass	0.25 - 0.73	New Zealand	Woodfield 1999
	0.4	New Zealand	Easton et al. 2002
	0.7 (summer/autumn)	New Zealand	Easton et al. 2002
	0.1 (spring)	New Zealand	Easton et al. 2002
	0.5	Europe	Wijk and Reheul 1991
Annual ryegrasses	1.5	New Zealand	Easton et al. 2002

Tall fescue	0.1 to 0.55	Europe	Veronesi 1991
Lucerne	0.26	Central USA	Hill et al.1988
	0.18 and 0.22	Northern USA	Holland and Bingham, 1994
	1.0	USA	Loiselle 1992
White clover	1.21 – 1.49	New Zealand	Woodfield 1999
	0.4	New Zealand, South Africa, Czechoslovakia	Caradus 1993
	0.6	New Zealand	Woodfield and Caradus 1994

- Hybrid breeding systems: The majority of perennial grass species are outbreeding and so the development of inbred lines to produce a hybrid with increased heterotic vigour has been a challenge (Woodfield and Brummer 2001). Two systems have been explored with limited success and as yet there are few commercialised options.
    1. Semi-hybrids – in some outcrossing species such as perennial ryegrass severe inbreeding depression occurs when developing inbred lines and so hybrid vigour is better captured by crossing populations with very different genetic backgrounds (Brummer 1999). The production of a semi-hybrid as first generation certified seed could be achieved by sowing a mixture of basic seed of two cultivars (Barrett et al. 2010).
    2. True hybrids which involves the use of cytoplasmic male sterility systems which result in failure to produce functional pollen (Havey 2004) has been successfully used in field crop breeding (Bohra et al. 2016). Use in perennial outcrossing forage crops is still theoretically possible but has not yet become a commercial reality (Islam et al. 2014).
- Speed breeding: By using prolonged photoperiods the developmental rate of plants can be accelerated to allow multiple generations per year rather than the 1 or two for field grown plants (Watson et al. 2017). This has been achieved with annual crops plants, but for perennial outcrossing crops only computer simulations have been used and these show that additional genetic gains can be achieved from speed breeding, but methods to mitigate inbreeding are required for optimal outcomes (Jighly et al. 2019).
- Phenotyping systems: Persistency is an important evaluation criterion for perennial forage breeding programs along with forage yield and quality, but can be difficult to measure by eye. Recent advances in digital photography and image analysis software, remote or proximal digital imaging provides opportunities for improved vegetation data collection and analysis (Luscier et al. 2006; Walter et al. 2012) including persistence where ground cover is imaged remotely to determine persistency (Borra-Serrano et al. 2018).
- Genomic selection: Genomic selection has been successfully used in animal and crop breeding and has the potential in forages for selecting key traits that are difficult or expensive to assess, or can only be measured after a period of time, e.g. plant persistence. The main benefits expected from genomic selection in forage grasses and legumes are to increase selection accuracy, reduce cycle time, and potentially reduce evaluation costs per genotype (Resende et al 2014). A number of publications have propositioned that genomic selection will deliver major advances in improved yield, quality and persistence

of grassland species (Hayes et al. 2013). However, to date the promise of genomic selection in forages is yet to be realised.

- Gene editing techniques such as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) allow for the insertion, removal or replacement of genes at predetermined sites in the genome (Richter 2016) and is being used to precisely design crop plants (Wang et al. 2014; Komor et al. 2017). The same could be achieved for grassland species (Fritsche et al. 2018). In many countries gene edited plants are still viewed as genetically modified and subject to regulation, although there is increasing momentum for them to be de-regulated (Pei and Schmidt 2019). This has occurred already in some countries where gene edit has not resulted in inserting foreign DNA.
- Transgenics plants have been genetically engineered or modified using recombinant DNA techniques to create plants with new traits and characteristics. This technology has been used extensively in crop plants such as soybean, cotton, maize and canola but while experimented with in grassland and forage species there are few commercialised examples. The notable exceptions are for lucerne with Roundup Ready alfalfa® and HalvXtra® (low lignin) alfalfa both marketed (Undersander 2010), making up about 30% of the total lucerne market in USA.

Concluding comments

Sustainably increasing grassland productivity through creating more from our resources while staying within environmental limits is a key to raising living standards globally. However, grassland farming faces significant challenges from consumers, environmentalists, government policies, and new technical options. Integrating the large number of agritech developments into current pastoral systems will in itself provide challenges to farmers and society as a whole. Yet without that being achieved threats to the sustainability of grasslands will increase. There is much for us as grassland researchers to understand and manage so that the world's grasslands both natural and man-made have an enduring future.

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