Forage crop systems: challenges, opportunities, and technology transfer

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Abstract
Over two-thirds of all agricultural land in the USA is grasslands, with a large economic value as well as many ecosystem benefits. Forage crop systems enjoyed maximum popularity in the middle of the 20th century after the Dust Bowl era, with pastures and hay fields recognized for their soil conservation benefits. The land-grant college system provided significant funding, infrastructure, and support for a relatively large number of forage-animal scientists. Forage crop system advances ranged from fundamental research that elucidated plant processes to applied research that developed best management practices. As the country moved from a significant rural population to a mostly urban/suburban population, both federal and state support for agricultural research declined. The heterogeneous decline in support for agricultural research has been strongly correlated with the power of commodity organizations and the perception of the commodity by the agricultural community and the general public. Forage crops lack a commodity status and are the least relevant when university research and extension cuts to programs and faculty are mandated. While forage crops are a prime example of a dual purpose crop, providing both agricultural income and ecosystem services, the general public often views all conventional agriculture as unsustainable, while at the same time reluctant to pay for valuable ecosystem services. Perennial forages as biofuel crops are seen as promising for the future of forage research by some, and seen as a death blow to forage-animal scientists by others. Increased communication with stakeholders and legislators is essential to have any hope for increasing state and federal support for grassland and forage crop research.

Key words
Grazing, Plant breeding, Legume, Grass, Biomass, Conservation

Introduction
Forage crop systems are the integrated combination of animal, plant, soil, and other environmental components managed to achieve a productive agro-ecosystem (Cherney and Kallenbach, 2007). Grasslands constitute more than two-thirds of all agricultural land in the USA, with an economic value estimated at about $45 billion annually (Sanderson *et al*., 2012). Forage crops provide one half to almost all the total feed requirements of ruminants and also serve as one of the primary resources that allow effective nutrient management planning. Only 7% of the total permanent grassland is in the eastern half of the USA (Sanderson et al., 2012). Well over half the New York State crop acreage is in perennial forages. The value of field crops in NY is similar to the value of milk, and 60% of field crop value was derived from corn silage and perennial forages. Nevertheless, the value of forages is generally seen as insignificant compared to milk. Generations of forage crop researchers have focused on maximizing forage and animal production, while the challenge for the future is to increase and sustain all ecosystem services of multi-functional grasslands (Kemp and Michalk, 2005). Management to provide ecosystem benefits and economic return can be complementary, but in many cases the desired outcomes are competitive (Nelson *et al*., 2012).

Genetics and Plant Breeding Advances
Forage breeding typically starts in the public sector and moves to the private sector, only if the product has high enough value and sufficient seed production to sustain a commercial market. Genetic gains in forage species have been lower than with grain crops for several reasons. The primary reason, however, is that forage crops are not considered a commodity of significant value, and therefore forage crops and forage-animal activities lack commodity and general public support. Since there are many potential forage crop species, and forages can be used as hay, pasture, or silage, an individual breeding program can only address a small subset of these issues (Brummer *et al*., 2009). Some improvements in forage nutritional value have been documented in forages in the past (Casler and Vogel, 1999; Wilkins and Humphreys, 2003), and the authors pointed out the need to document increased animal performance to achieve rapid adoption of new cultivars.

Alfalfa is the primary forage crop to have a major commercial sector focusing on genetic improvements in the USA. A critical mass of breeders, entomologists, pathologists, and agronomists contributed to significant gains in persistence through the development of insect and disease resistances and cold and grazing tolerance (Brummer *et al*., 2009). This same critical mass of scientists contributed to the development of low-lignin alfalfa (Reddy *et al*., 2005). Forage breeding in the future will need to focus more on the environment, with a better balance between energy and protein content to minimize N excretion (Kingston-Smith and Thomas, 2003). Forage crops generally lack the capital investment required, and the genetic simplicity desired, to attempt improvements using transgenic approaches. Unlike many countries, there is little opposition to biotech traits by USA growers, with the exception of organic growers. A significant faction of the public, however, remains skeptical of transgenic crops.

Another exception to low genetic gains in forages is the rapid expansion of forages for bioenergy (Fribourg, 2008). Government policies, along with moderate interest from the general public providing venture capital, resulted in pressure on forage breeders to improve dedicated bioenergy crop traits. Many millions of dollars provided ample incentive for forage breeders to refocus on bioenergy feedstock traits, which are typically the opposite of forage quality traits. The massive infusion of capital allowed development of transgenic approaches, with advances reported recently (Casler *et al*., 2015b; Lipka *et al*., 2014; Lu *et a*l., 2013; Ramstein *et al*., 2015). Sustainable biomass feedstock research and production has also focused on the use of marginal agricultural lands, to minimize competition with food and feed crops (Stoof *et al*., 2015). Some marginal soils, however, are inappropriate for biomass harvesting, and only suited to grazing or conservation and recreational purposes (Wells et al., 2003).

Pastures

The traditional goal of pastures is to provide sufficient quantity and quality of forage to sustain a particular group of livestock and generate a profit for the farmer. Grazing research typically involves the use of herbivores, but can consist primarily of development of forage cultivars that are either more palatable or generally higher in forage quality (Casler *et al*., 2015a; Casler *et al*., 2014). Forage and grazinglands must now focus on the wider issues of ecosystem functions and ecosystem services (Lemaire *et al*., 2005). The increasing importance of multifunctionality in grasslands cannot be effectively studied with standard short-term controlled agricultural research. Yet research funding has shifted its focus to short-term commercial advantage rather than public good (Alston *et al*., 1999). Grazing researchers are simultaneously dismissed as scientifically unsophisticated and irrelevant by the fundamental scientist, and considered impractical and not relevant by the end user (Sollenberger, 2015). In reality, grazing research projects are typically long term, requiring a range of fundamental to applied science, making this research more complex than that of the typical "fundamental" research.

Forage Management

Reduced funding for applied research and extension in forages has accelerated interest in developing computer-based tools for decision making (Hannaway *et al*., 2005). Decision support computer programs for crop and livestock systems were developed starting in the early 1980's, but it was not until recently that management decision aids became readily available to farmers. For example, Cornell's forage selection tool is made up of several programs that access databases to provide forage species recommendations and take into account the specific soil type and the intended forage use. Another series of programs has been developed to estimate neutral detergent fibre composition of pure alfalfa and binary stands of alfalfa-grass in NY (Parsons *et al*., 2006). Species composition of binary mixtures can be evaluated in cell phone photos using artificial intelligence software (McRoberts *et al*., 2012). Both systems will be available soon to farmers through smart phone apps. The future is likely to include rapid development of spectral analyses of forages in the field for yield (Islam and Garcia, 2014), quality (Post *et al*., 2007), insect, and disease evaluation using unmanned aerial vehicles. It is desirable for any new decision-making tools to be farm-size neutral, allowing all farmers access to them.

Forage Crop Extension and Outreach

The goal of extension education universally is to help people improve their quality of life and maintain viable, profitable agricultural ventures (Murray, 1999). Extension education facilitates technology transfer. Technology transfer requires: 1) information generation, 2) an informed target audience, and 3) implementation by the target audience (Undersander, 2005). In reality, extension faculty duties at USA universities range from 100% extension education responsibilities to nearly 100% information generation responsibilities, depending on the university and the region of the country.

Sollenberger (2015) suggests that we might limit our target audience to the most progressive farmers ("change agents"), and let their success extend the technology, instead of delivering the message to anyone who will listen. This strategy would focus applied research/extension efforts on successful implementation of technology on the most progressive farms, which may be the most efficient use of a small and shrinking set of forage personnel. On the other hand, forages provide great value to society and to agriculture, and the public becomes aware of forages primarily through extension education activities. Regardless of delivery method, implementation is critical.

Undersander *et al*. (2009) reported that over 65 full-time equivalent (FTE) of forage extension positions were lost across the USA from the period of 1987 to 2007. Rouquette et al. (2009) estimated that there will be a 47% decrease in forage-animal extension FTE scientists in the USA during the 20-year period from 1998 to 2018. Because forage-animal systems is a nebulous commodity, extension positions in this discipline will probably be the least likely to be considered for replacement when such positions open up.

Land-grant system and forages

The Morrill Act of 1862 and subsequent amendments funded educational institutions in the USA by granting federally-controlled land to states in order to sell it and raise funds to establish "land-grant" colleges. Their original mission was to focus on teaching agriculture, science, military science, and engineering. Coupled with these colleges, the 1887 Hatch Act created the agricultural experiment station program. For well over 100 years, scientists working at state agricultural experiment stations and land-grant colleges have conducted research to improve the quality of life for its citizens, and almost everyone agrees that the system has been very successful. Land-grant colleges became the foundation of modern USA agricultural productivity and efficiency. The success of land-grant colleges in increasing agricultural productivity lead to a rapid decline in rural population, and the land-grant system gradually became a casualty of its own success (Fribourg, 2003).

Federal support of land-grant colleges has declined substantially during the past 40 years, forcing states to provide much of the land-grant college support. In the increasingly urban states, competition from primarily urban programs claimed more tax revenues, so many states lost touch with agricultural research and became less willing to support it. By 1990, both states and the federal government were significantly reducing funding for agricultural research (Alston *et al*., 1999), encouraging scientists to compete for extramural funding sources. Traditional federal formula funds for states were gradually replaced by competitive research programs. Competitive grants are typically for relatively short-term research. Consequently, perennial forage and grassland research, which normally requires long-term research, is one of the research areas most negatively impacted by the shift away from formula funds.

Funding now has shifted from state to grant-funded areas, even though state agricultural experiment station mission statements appear to have remained intact (Rouquette et al., 2009). The shift in funding support has impacted some disciplines much more than others. One of the areas with very few extramural funding opportunities is forage crops. Faculty appointments also have gradually shifted to disciplines and commodities with the most extramural funding support, supported by vocal commodity groups and other vested interest groups. Public support for the experiment station model may eventually be undermined by faculty appointments and programmatic directions that ignore or minimize the value of providing products and technology to traditional clientele (Sollenberger, 2015).

New Funding Paradigm

To counteract the trend towards discipline-oriented research (Maplestone and Blundell, 1995), research entities have been created to attempt large, interdisciplinary research projects at regional, national, and international scales. The European Commission initiated the Joint Programming Initiative (JPI) in 2008, to increase the value of national and EU research funding through joint planning and implementation of research programs. For example, the initiative on Agriculture, Food Security and Climate Change (FACCE-JPI) brought together 21 countries to address the overlapping challenges of sustainable agriculture, food security, and climate change, through interdisciplinary research (FACCE-JPI, 2015). Also in 2008, the National Institute of Food and Agriculture (NIFA) was formed within the USDA, to integrate scientific disciplines, as well as to integrate research, education and extension activities. While forage and grassland issues appear to be well represented in JPI programs, less than 0.2% of NIFA's nearly $800 M research and education budget has been dedicated specifically to forage and grasslands.

Impact of Funding Strategies on Forage Crop Research

The use of forage crops as cellulosic biofuel is often seen as a bright spot for the future of forage crop research. The 907 million tonnes (Billion-ton supply) of biomass that is estimated to replace 30% of USA petroleum needs (Perlack *et al*., 2005) would likely include about 15 million ha of grasslands (Undersander et al., 2009). While this could have a significant positive impact on grasslands, it could also have a potentially large negative impact on forages. Due to the lack of funds for forage crop research, many forage workers have migrated toward the more fundable issues, which are not typical agricultural production. Currently, there appears to be ongoing FTE transition from retiring forage crop researchers, who pursued funding in peripheral areas such as biomass, to newly-hired biomass researchers who will have peripheral responsibilities for forage crop research. While forage researchers constantly look for creative ways to supplement their forage research programs, biomass researchers with minor forage crop responsibilities will be much less likely to pursue forage research projects that provide limited funding support or university overhead.

Multiple authors have pointed out that although forage crops promote clean air and water, and reduced flooding and erosion, the general public is unaware of forages as a valuable commodity (Undersander et al., 2009; Rouquette *et a*l., 2009). In New York State for example, the dollar value of perennial forages exceeds the combined value of all fruit and all vegetables, excluding the environmental benefits of forage crops. Yet there are approximately 15-fold more fruit and vegetable FTE scientists at Cornell University, compared to those in forage crops. From 2008 to 2018, it was estimated that almost half of the existing forage utilization scientists in the USA will retire (Rouquette, *et al*, 2009). Unfortunately, many of these forage scientists are not being replaced.

Conclusions

Forage crops are a major renewable natural resource with significant ecosystem services in the USA but they receive virtually no recognition nor respect among University and Government administrators. Society wants farmers to adopt sustainable practices, but as of now are unwilling to pay for it. Needs assessments over the past 20 years have been relatively consistent for forage and grasslands. Forage crops and the forage-animal system are not seen as a commodity, and therefore will continue to lack commodity support. At a time when we should be returning to a more integrated forage-animal research paradigm, the future is likely to see a continued decreasing allocation of scientists to forage-animal programs. If universities hire replacements, position descriptions will focus on fundable themes that include significant indirect cost recovery. Forage researchers may be found primarily in industry in the future. It is up to us, forage researchers, to increase communication with stakeholders and legislators on the importance of forage crops to agriculture and society as a whole. We must identify "legislative champions" for forage crop systems who will advance the importance of increased state and federal funding for this unsung hero of animal agricultural systems.

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