Transitioning to Multiple-use Polyculture Grassland-derived Bioenergy Feedstock Systems

Muir, J.P.*†, Foster, J.L.*, A. Falk., Weiss, S., Pitman, W.D. **, Alison, W. **, Naumann, H.D., Bow, J.R., Shadrock, C.,† * Osei, E.,† Lasater, O.†*

* Texas A&M AgriLife Research & Tarleton State University; † Tarleton State University; **Louisiana State University Agricultural Center

Key words: forage; bioenergy; legume; bunchgrasses; native

Abstract

We argue that research and development of grassland-derived bioenergy feedstock (GBF) has focused unduly on dedicated monospecific biomass systems to the detriment of more stable multiple-use multispecies grasslands. This has retarded GBF adoption as a viable, sustainable contribution to renewable energy production in North America. We hypothesize that focusing on multiple-use GBFs will foster greater feedstock availability for nascent renewable energy generation while minimizing financial risk to grassland husbandry during market transitions from current grazing systems to more flexible business models. Our hypothesis is that source and demand are more likely to develop simultaneously under less risky multiple-use grassland management. We review what little research exists detailing such multiple-use systems that include GBF as a major component. We propose that more federal and private sector research funding should focus on perennial forage legumes and bunchgrasses for multiple uses including forage, bioenergy, grassland restoration, wildlife, and ecosystems services such as hydrology, carbon capture and biodiversity. These data cover both native and introduced species in cultivated pastures as well as managed rangeland and native grassland. We conclude that more research effort should be focused on multiple-use GBF in order to identify individual species, mixtures and ecosystems that provide flexibility in the face of unpredictable grassland environments and volatile energy markets.

Introduction

We propose that developing multiple-use grasslands will contribute positively to greater production and demand for grassland-derived bioenergy feedstocks (GBF). This will also mitigate the environmental costs of converting grasslands to cultivated annual bioenergy row crops and second-generation perennial monocultures (Nunez-Reguiro et al. 2021). Despite much research, public hyperbole and the sound logic directed at diverting pasture and rangeland vegetation from grazing into bioenergy feedstock production (Wilbrink 2021), demand for GBF in North America has not materialized in recent decades. This may be a case of "which comes first, the chicken or the egg." We hypothesize that a major barrier limiting bio-industrial demand for GBF is lack of guaranteed sources. However, GBF cannot develop in the absence of a steady, dependable demand. Developing grassland ecosystems with flexibility to exploit various market demands, including cattle, GBF, wildlife, and ecosystems services may resolve this catch-22.

Much of the cause for this impasse arose from federal bioenergy policies and related research funding priorities within the United States Departments of Agriculture, Energy and Transportation. The federal focus (and of the grant peer reviewers) in past decades has been on developing dedicated bioenergy monocrops. The logic was that, to guarantee biofuel supplies, research on GBF had to focus on single-purpose, dedicated GBF systems. The millions of federal dollars spent on switchgrass (*Panicum virgatum*) development are a prime example. Although this native bunchgrass is widely adapted, numerous cultivars adapt to diverse edaphoclimatic conditions, and management requirements have been fine-tuned, its usefulness as a monoculture for other purposes such as grazing, wildlife or ecosystem services dependent on plant and animal diversity and versatility is limited.

Short-sighted federal priorities chose switchgrass monoculture from among many other candidate species and systems. Its appeal came primarily from wide adaptation and a robust growth habit that lends itself to mechanized harvest. Being a native appeased the non-agricultural public possessing little understanding of other key factors beyond weedy invasiveness. These should include the value of biodiversity in ecosystem stability, adaptability and productivity. They should also include physiological and market flexibility of the species and mixtures that match volatile food and energy markets.

Methods

We reviewed the literature as well as our own research for insights into multiple-use grasslands that include GBF, with particular focus on North America. We included cultivated pasture as well as managed rangeland and native grasslands. We attempted to look beyond simple biological factors into what grassland managers find challenging and markets might demand.

Results and Discussion

Landscape design

Managed grasslands in free-market economies rarely follow facile landscape design. They are, rather, based on haphazard historical preferences and market drivers. Dale et al. (2016) argued for coordinated, top-down landscape designs when developing sustainable bioenergy production systems. In a free-market economy, this is a highly unlikely scenario. Policy decisions are important drivers of land use as USDA programs often influence profitability of particular crops and conservation options. Across much of Texas, wildlife-based enterprises complement range-based cattle production. We hypothesize that transitioning from cattle-centric systems to GBFs based on flexible, multiple-use, market-responsive grassland management would be less prone to climatic, environmental and economic vagaries.

Cultural priorities

Rural cultures based on grassland agriculture are often so ingrained that even small changes, including new species, management or market opportunities, face resistance from ingrained grassland management practices. Novel opportunities such as GBF or ecosystems services that de-emphasize a traditional ranch culture in grassland systems will need to consider these entrenched land management traditions (Maher et al. 2021). Introducing innovations to rangelands and their inhabitants, especially, need to consider the diverse human perspectives (Roche 2021).

Flexible species & systems

Understandably, most forage species have been historically selected based on nutrient production and availability of these nutrients (digestibility) to herbivores, primarily domesticated ruminants. Fermentation that results in alcohol or biogas from GBF parallel microbial breakdown of long carbon chains in the rumen by microorganisms, allowing for useful exchange of ruminant and bioenergy research (Li et al. 2022). However, maximizing cellulosic production in GBF for pyrolysis requires identifying species and management practices that maximum biomass accumulation that, due to maturity, is largely useless for ruminant production. Likewise, reducing grassland plant species diversity to maximize dry matter productivity also reduces its usefulness for other purposes such as wildlife and other animals (pollinators especially) as well as ecosystem services such as soil microorganism diversity and stability, that thrive in biodiverse environments.

Table 1. Average dry matter (DM) yield (kg ha^{-1} $year^{-1}$) per plant or area and nitrogen (N) content/concentration on a DM basis of selected native and introduced grassland species in Texas when harvested as forage (repeated harvests throughout season) or bioenergy feedstock (single harvest in late season).

Grasses	Forage DM	Bioenergy DM	Forage N %	Bioenergy N %
Panicum virgatum	6,720	8,570	1.24	0.39
Schizachyrium scoparium	4,943	8,663	0.74	0.67
Tripsacum dactyloides	17,520	19,453	0.92	0.85
Bouteloua curtipendula	2,132	5,002	1.38	0.67
Sorghastrum nutans	9,985	16,184	0.93	0.70
Cynodon dactylon	5,738	8,282	1.89	0.69
Andropogon gerardii	5,371	23,424	1.48	0.90
Bothriochloa laguroides	7,575	4,801	1.22	0.53
Cenchrus myosuroides	20,100	12,116	1.25	0.68
Muhlenbergia reverchonii	2,400	5,243	1.22	0.59

Average	8,248	11,174	1.23	0.67

Muir et al. 2010; Wilson et al. 2013; preliminary data 2022

Harvesting some grassland species for ruminant production while leaving other species as GBF because they are unsuitable for animal feeds diversifies grassland utility, especially for wildlife habitat. Our preliminary results in Texas indicate that N content in grasses harvested for forage declines 44% if harvest is delayed until maximum DM accumulation, which increases by autumn in 80% of species (Table 1). For example, phytochemicals that inhibit rumen and biogas fermentation (Rashama et al. 2021) are not an issue for pyrolysis. In another example, in large tracts of North American grasslands, grazing mesquite (*Prosopis juliflora*) or juniper (*Juniperus* spp.) understory with cattle or wildlife while harvesting the wood for pyrolysis, solves the issue of invasive native trees rich in phytochemicals such as hydrolysable tannins or terpenes toxic to ruminants.

Grass and forbs complementarity

Most research indicates that grasslands are more stable and productive with greater diversity. Grasses in general provide greater biomass while forbs, most notably legumes, enhance nutritive value and ecosystem services and decrease industrial fertilizer requirements. This tends to be the case in cultivated pasture (Jaramillo et al. 2021; Tahir et al. 2022) as well as rangeland (Young and Koerner 2022).

Advantages of diversity

Establishing and maintaining multi-specific grassland mixtures offers several advantages over monocultures (Taraborelli et al. 2022). Pastures, rangeland and native prairies comprised of myriad grass and forb species tend to be more stable and productive, extend grazing seasons, support greater animal and soil microbiome diversity and provide more ecosystem services (Richwine 2021). Including multiple canopies, such as brush and trees, increases these advantages even further, especially with ecosystem services such as healthy soil microbiomes, wildlife diversity and more feed for multi-species ruminant herds (Kreitzman et al. 2022; Costa et al. 2021).

Challenges of mixtures

Establishing and maintaining GBF polycultures for multiple uses is not always easy. Interspecific competition can be such an issue that some species, especially slower-establishing forbs, end up contributing very little to the mixture (Richwine 2021). Using aggressive annuals as nurse crops for more slowly establishing perennials can be detrimental, especially forbs, rather than contribute to final diversity.

Multiple uses

Grasslands that include GBF as one among many market-outlet options for their plant material require flexible opt-out options from the grassland husbandry perspective (Sant'Anna et al. 2021). This makes steady supply for energy plants challenging. Fei et al. (2022) argued for flexibility in bioenergy technologies (e.g., pyrolysis, fermentation to generate ethanol or gasification) along with varied feedstocks, including agricultural by-products, as a counterbalance for unpredictable GBF supplies.

Perennial versus annual systems

Permaculture GBF incorporating diverse perennial species tend to be more stable over time and provide greater ecosystems services (Hirschfeld and Van Achker 2021). Annual systems typically involve intensive approaches based on high input levels and competition with other crops for land suitable for cultivation.

Trade-offs

Focusing on GBF production can result in trade-offs, not all positive (Vera et al. 2022). Positives include potentially reducing greenhouse gas emissions by replacing petrochemical energy or ruminant methane emissions with bioenergy. Competing with food production, a clear negative, can be avoided by producing GBF with perennial, stable systems on land, such as silvopasture or hillsides, that is not suitable for annual row crops. These include replacing annual row crops in marginal climates and inappropriate landscapes or soils. Along with sustainability advantages of perennial vegetation in marginally productive environments, the economic opportunities provided by native wildlife species in appropriately diversified grasslands can off-set production advantages of intensively cropped monoculture systems in fragile or less-productive environments.

Conclusions and/or Implications

If we hope to foster greater future GBF contribution to bioenergy, we must modify our current strategy. We may be able to do this by focusing greater attention on multiple-use polyculture grassland production systems in which GBF is only one of many uses. We can start by identifying individual species or diverse grassland communities that exhibit flexibility in yields and nutrient contents that can be channelled to multiple uses driven by ever-changing market demands. The perfect forage may not be the best GBF or provide the most ecosystem services. Compromise species, ecotypes, cultivars or mixtures of these may not be the best forage or GBF but may be the most appropriate for meeting variable market needs. As such, future research and demonstration grasslands should include forage data collection alongside GBF or ecosystems services evaluations. Diverse, adaptable grasslands may be the ideal future grassland in many environments.

References

Costa, H.C.M., Benchimoi, M., and Peres, C.A. 2021. Wild ungulate responses to anthropogenic land use: a comparative Pantropical analysis. Mammal Rev 51: 528-539. https://doi.org/10.1111/mam.12252

Dale, V.H., Kline, K.L., Buford, M.A., Volk, T. A., Smith, C.T., and Stupak, I. 2016. Incorporating bioenergy into sustainable landscape designs. *Renewable Sustainable Energy Rev* 56:1158-1171. https://doi.org/10.1016/j.rser.2015.12.038

Fei, C.J., Kung, C., McCarl, B.A., and Fan, X. 2022. The optimal development paths of competing bioenergy technologies: An economic and environmental evaluation (May 16, 2022). Available at SSRN: https://ssrn.com/abstract=4111458 or http://dx.doi.org/10.2139/ssrn.4111458

Hirschfeld, S. and Van Achker R. 2021. Review: ecosystem services in permaculture systems. *Agroecology Sustanable Food Syst 45: 794-816.* https://doi.org/10.1080/21683565.2021.1881862

Jaramillo, D.M., Sheridan, H., Soder, K., and Dubeux, Jr., J.C.B. 2021. Enhancing the sustainability of temperate pasture systems through more diverse swards. *Agron* 11(10), 1912; https://doi.org/10.3390/agronomy11101912

Kreitzman, M., Eyster, H., Mitchell, M., Czajewska, A., Keeley, K., Smulker, S., Sullivan, N., Verster, A. and Chan, K.M.A. 2022. Woody perennial polycultures in the U.S. Midwest enhance biodiversity and ecosystem functions. *Ecosphere* 13: January 2022 e03890. https://doi.org/10.1002/ecs2.3890

Li, Y., Xu, Y., Xue, Y., Yang, S., Chang, Y, and Zhu, W. 2022. Ethanol production from lignocellulosic biomass by co-fermentation with *Pecoramyces* sp. F1 and *Zymomonas mobilis* ATCC 31821 in an integrated process. Biomass Bioenergy 161: 106454. https://doi.org/10.1016/j.biombioe.2022.106454

Maher, A.T., Quintana Ashwell, N.E., Maczko, K.A., Taylor, D.T., Tanaka, J.A. and Reeves M.C. 2021. An economic valuation of federal and private grazing land ecosystem services supported by beef cattle ranching in the United States. *Transl Anim Sci* 2021.5:1-15 doi: 10.1093/tas/txab054.

Muir, J.P., Lambert, B.D., Greenwood, A., Lee, A. and Riojas, A. 2010. Comparing repeated forage bermudagrass harvest data to single, accumulated bioenergy feedstock harvests. *Bioresource Tech* 101:200-206.

Nunez-Reguiro, M.M., Siddiqui, S.F., and Fletcher Jr., R.J. 2021. Effects of bioenergy on biodiversity arising from land-use change and crop type. *Conservation Biol* 35: 77-87. https://doi.org/10.1111/cobi.13452

Rashama, C., Ijoma, G.N., and Matambo, T.S. 2021. The effects of phytochemicals on methanogenesis: insights from ruminant digestion and implications for industrial biogas digesters management. *Protein Cell* 20: 1245-1271.

Richwine, J.D. 2021 Interseeding native warm-season grass pastures. Doctoral dissertation University of Tennessee. "Interseeding Native Warm-Season Grass Pastures" by Jonathan D. Richwine (tennessee.edu)

Roche, L.M. 2021. Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands* 43: 151-158. https://doi.org/10.1016/j.rala.2021.03.006

Sant'Anna, A.C., Bergtold, J.S., Shanoyan, A., Caldas, M.M. and Grando, G. 2021. Deal or no deal? Analysis of bioenergy feedstock contract choice with multiple opt-out options and contract attribute substitutability. ICAE 2021 International Conference of Agricultural Economist. 17-31 August 2021. Online. 0-0_Paper_19309_handout_50_0 (1).pdf

Tahir, M., Li, C., Zeng, T., Xin, Y., Chen, C., Javed, H.H., Yang, W., and Yan, Y. 2022. Mixture composition influenced the biomass yield and nutritional quality of legume-grass pastures. *Agron* 12(6), 1449; https://doi.org/10.3390/agronomy12061449

Taraborelli, P., Carrasco, N., Malaspina, M., Domínguez, M.C., Belaus, A., López, A., Scavone, A.S., Barbera, A. and Zamora, M.Y. 2022. Evaluation of agrobiodiversity and its trophic interactions as an indicator of sustainability in productive systems. *J Environ Biol* 7(1): 006-013. DOI: 10.17352/ojeb.000027

Vera, I, et al. 2022. Land use for bioenergy: Synergies and trade-offs between sustainable development goals. *Renewable Sustanable Energy Rev* 161: 112409. https://doi.org/10.1016/j.rser.2022.112409

Virginia, H., Dale, K.L. Kline, M.A. Buford, T.A., Volk, C., Tattersall Smith, I.S. 2016. Incorporating bioenergy into sustainable landscape designs. *Renewable Sustain Energy Rev* 56: 1158-1171.

Wilbrink, J. 2021. The controversies of bioenergy.: a multi criteria decision analysis of bioenergy feedstocks. Thesis, Delft University of Technology. http://resolver.tudelft.nl/uuid:a35a706d-6e9f-4113-bfab-ec1f2dcd338d

Wilson, D.M., Dalluge, D.L., Rover, M., Heaton, E.A. and Brown, R.C. 2013. Crop management impacts biofuel quality: influence of switchgrass harvest time on yield, nitrogen and ash of Florence pyrolysis products. *Bioenergy Res* 6: 103-113. https://doi.org/10.1007/s12155-012-9240-0

Young, A.L. and Koerner, S.E. 2022. Understory dynamics in North Carolina longleaf pine savannas: Biodiversity, dominance, and biomass. *J Veg Sci* 33: March/April 2022 e13126. https://doi.org/10.1111/jvs.13126