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Comparing Biomass Yields of Low-Input High-Diversity Communities with Managed Monocultures Across the Central United States

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Abstract Biofuel cropping expansion is increasing pressure on food, grazing, and conservation lands. Debate over the efficacy of converting diverse native plant communities to managed monocultures prompted us to explore the extensive crop and ecological site productivity databases maintained by US Department of Agriculture-Natural Resources Conservation Service. We compared annual net primary productivity (ANPP) of diverse native plant communities to ANPP of alfalfa (*Medicago sativa* L.) in Nebraska, Kansas, and Oklahoma; to coastal bermudagrass (*Cynodon dactylon* [L.] Pers.) in northern and central Texas; and to buffelgrass (*Pennisetum ciliare* [L.] Link.) in extreme southern Texas. In only 21% of the 1,238 sites in Nebraska, Kansas, and Oklahoma did native communities produce more or equivalent ANPP compared with managed alfalfa or coastal bermudagrass. In contrast, southern Texas native communities had greater ANPP than did buffelgrass at 81% of the sites. Regression analyses based on these results suggested that managed switchgrass (*Panicum virgatum* L.) ANPP would consistently exceed native community ANPP. We identified the type of sites that could remain in diverse communities or be converted to diverse communities and have productivity as great as or greater than highly managed monocultures of alfalfa, coastal bermudagrass, or buffelgrass. However, because of the low ANPP on these sites, biomass production may not be the optimal use of such sites. These lands may be better suited to providing other ecosystem services.

Keywords Annual net primary production · Biomass · Biofuel · Low input high diversity · Switchgrass

Abbreviations

ANPP	annual aboveground net primary productivity
CRP	Conservation Reserve Program
LIHD	low-input, high-diversity system

Introduction

The US Departments of Agriculture (USDA) and Energy (DOE) estimate that the USA will require one billion megagrams (Mg) of biomass annually to displace 30% of current US petroleum demand with biofuels [1]. This has led to debate over how best to produce the needed plant matter, including determining optimal species, cropping systems, and appropriate land to be used for biofuel production, as well as whether biofuel mandates should exist at all [2–7]. Central to the debate is the concern that increasing our agricultural footprint through biofuel crops produced with a traditional agricultural approach will take food and conservation lands out of production, negating the goods and services we currently derive from those lands [8, 9].

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Conversion of large acreage in the USA from diverse native plant communities or restored prairie to monoculture grasses or legumes for biofuel production raises concerns about sustainability, including temporal and spatial yield stability over different climatic conditions, net energy efficiency, loss of wildlife habitat, dependence on ecologically and economically costly fertilizer applications, soil erosion, loss of biocontrol and pollinator reservoirs, and disruption of biogeochemical cycles [9–14]. Globally, conversion of land to agriculture to meet food demand is expected to lead to a loss of one billion hectares (Bha) of ecosystem area and associated services by 2050 [2]. At the same time, land devoted to biofuel production could increase to 1.5 Bha by 2050 [12].

It is proposed that producing perennial biofuel crops on degraded agricultural land or otherwise "marginal" land will reduce competition with food crops, maintain wildlife habitat, and minimize effects on carbon storage [9, 12, 15]. However, no studies to date test the long-term sustainability of harvesting biomass on such lands. Recent ecological work suggests that low-input, high-diversity (LIHD) systems on degraded prairie and abandoned agricultural land have higher annual aboveground net primary productivity (ANPP) than do unmanaged monocultures grown on the same lands [9, 16]. ANPP is defined as the aboveground component of the net amount of carbon assimilated by a defined area of vegetation over a defined period of time [10]. In the course of this study, ANPP is discussed on an annual basis.

The conclusions reached by LIHD promoters are not robustly supported by other work. Comparisons of ANPP between mixed plant communities and monoculture plant stands differ by site, species, and management [17–20]. The ANPP of single species systems may be lower than the ANPP of the diverse communities they replace [9, 10, 12]. Other grassland studies show ANPP decreases with increasing diversity [20–22]. In a meta-analysis of natural grassland ecosystems, no significant effect of species richness was demonstrated on ANPP [19]. Similarly, in a study of restored grasslands in southern Michigan, ANPP was comparable across all prairie sites, independent of species richness or prairie age [20]. In the Great Plains farmlands of the USA, highly irrigated and fertilized crops typically have greater ANPP compared with natural systems on the same soils [23]. Because all land management decisions have cascading impacts on the management of other lands [5, 24], land managers need some metric to determine which lands are most suitable for conversion to mixed species systems versus monocultures to improve forage, hay, or biofuel yield, while maintaining other ecosystem services.

If all available degraded land in the USA was converted to LIHD, the projected energy yields would supply only 10% of anticipated US energy demand [16]. With current conversion technology and assuming yields of 4 to 4.3 Mg ha^{-1} [9, 16], roughly 90 Mha of land would have to be converted to LIHD to replace 20% of current US gasoline consumption with cellulosic ethanol [4]. There are 184 million hectares (Mha) of agricultural land in the USA, with 15.8 Mha "idle" and 27.1 Mha in pasture [1]. To maintain current soil organic carbon levels under a no-tillage system, approximately 1.7 Mg aboveground biomass ha^{1} would have to be left *in situ* [25], increasing the necessary land base by 40% to meet both carbon and biomass goals. To give an idea of scale, the area of the state of Texas is 67.8 Mha; an area slightly smaller than two states of Texas managed as LIHD would offset only 20% of current US gasoline demand.

Actually, if ethanol is to be derived from a diverse, species-rich system, the land area requirement may be even greater. When ethanol yield is compared across plant species richness levels, projected ethanol yields decrease by up to 77% m^{-2} as species richness increases from 3 to 12.8 m^{-2} [21]. Utilizing enormous tracts of US land as LIHD would potentially displace food production systems to other localities, resulting in degradation of tropical ecosystems, loss of wildlife habitat, increased erosion, and accelerated carbon emissions [3, 15, 26].

Food and energy demands are increasing, and pressure is mounting to manage lands ever more efficiently to provide these products. As producers and policy analysts evaluate the impacts of land conversion, responsible decisions will depend on accurately identifying sites and soils where managed monoculture ANPP is sufficiently greater than native plant communities ANPP to warrant conversion. From an economic perspective, cropping biofuel feedstocks must bring greater profits to the land manager than do current systems of agriculture or conservation program payments. Economic analyses suggest that 17 Mha of US agricultural lands could be converted from current use (including 6.8 Mha of Conservation Reserve Program [CRP] land) to biomass production to produce 171 million Mg of biomass and greater profits than land managers are currently enjoying [27].

In this study, our first objective was to compare ANPP of low-input native plant communities to ANPP of managed monocultures of alfalfa (*Medicago sativa* L.) (Nebraska, Kansas, and Oklahoma, USA) or coastal bermudagrass (*Cynodon dactylon* [L.] Pers.) (Texas, USA) using data in the USDA-Natural Resources Conservation Service (NRCS) national ecological site database and the corresponding USDA-NRCS "non-irrigated crops" database (Fig. 1). Both species are candidates for second-generation bioenergy crops [28]. We determined the ANPP at which yields of the monoculture and the diverse native system were comparable. We posit that high-diversity systems yielding at or below this breakeven point should not be converted to alfalfa or coastal bermudagrass for biomass production because conversion to monoculture will

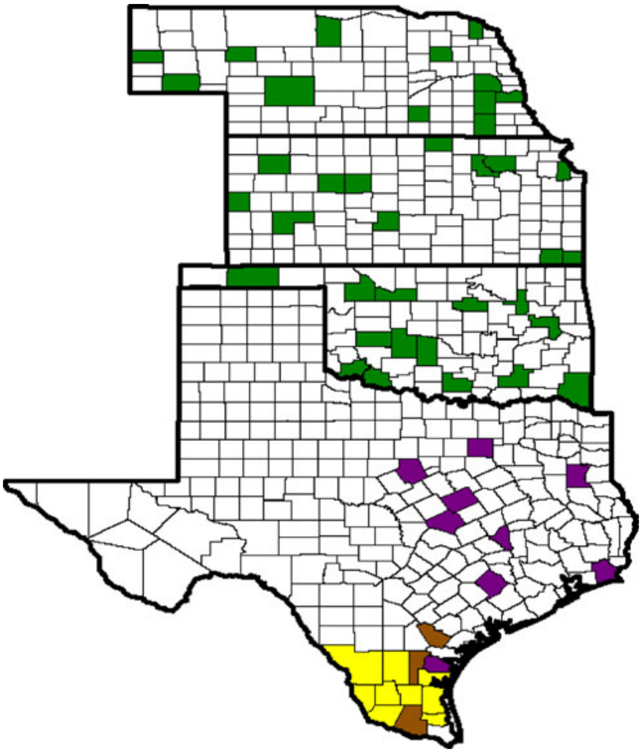


Fig. 1 Locations where native plant community aboveground ANPP was compared with alfalfa, coastal bermudagrass, or buffelgrass ANPP. Green counties had alfalfa comparisons; purple counties had coastal bermudagrass comparisons; yellow counties had buffelgrass comparisons. Brown counties had both coastal bermudagrass and buffelgrass compared with native mixtures. Native community ANPP was compared with switchgrass ANPP in all counties

lead to comparable or decreased ANPP at these sites and will be deleterious to ecological services (soil retention, carbon storage, wildlife habitat, etc.) currently provided by the grasslands established on these sites.

Our second objective was to fit regressions of mean switchgrass productivity values from multiple year measurements to the USDA-NRCS values for alfalfa (or coastal bermudagrass) and use these regressions to compare ANPP between managed switchgrass monoculture and native plant communities on the same soils in the same counties of these four states. The third objective was to do a similar comparison in the drought-prone region of southern Texas, comparing mean reported buffelgrass (*Pennisetum ciliare* [L.] Link) ANPP with native plant community ANPP.

Methods

Database, Cropping, and Site Selections

Underutilized resources for interpreting potential biomass production yields are included in the USDA-NRCS national ecological site database and the USDA-NRCS “non-irrigated crops” database, both of which can be accessed online through Web Soil Survey [20, 29] (Appendix 1). These databases are available for a massive number of soils in different counties for a wide range of latitudes, rainfall zones, and soil types. The USDA-NRCS national ecological site description database reports the dominant species, subdominant species, and estimated ANPP for the entire community on a given soil in a given county. Yields are based on well-managed land scenarios, and all vegetation (current year's production of leaves, twigs, and fruit of woody plants, as well as all herbaceous ANPP) is included in the estimate [29].

The USDA-NRCS unirrigated crops database includes mean annual productivity reported on various soil series within many counties for managed monocultures of common crops and forages relevant to that location, including alfalfa, coastal bermudagrass, and buffelgrass. Data reported are estimated average yields (ANPP) per acre of selected unirrigated crops under intensive agronomic management, which may include managing drainage and erosion, as well as appropriate seeding rates and soil management (tillage, weed control, nutrient input, etc.). Yield averages are based on farmer, conservationist, and extension agent records, as well as field and demonstration trials [29].

States identified in this analysis have a high potential of experiencing land-use conversion pressures as the US shifts to producing more biomass-based energy. We selected multiple soil series in each of 12 counties in Nebraska, 12 counties in Kansas, 14 counties in Oklahoma, and 21 counties in Texas (Fig. 1) to compare USDA-NRCS reported native plant community ANPP with monoculture alfalfa, coastal bermudagrass, or buffelgrass ANPP [29]. There is an inherent bias in this study due to the comparative nature of the work: because we required that all soil * county sites (henceforth, “sites”) have reported values for managed monocultures and native communities. Very low-quality sites with no reported ANPP for dry-land monoculture forage crops (alfalfa, coastal bermudagrass, or buffelgrass) were excluded from these analyses.

In Nebraska, Kansas, and Oklahoma, native communities tended to be dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), and sand bluestem (*Andropogon halii* Hack.). In Texas, big bluestem did not dominate any site but was subdominant at many little bluestem dominated sites. Other Texas dominants included Arizona cottontop (*Digitaria californica* [Benth.] Henr.) and false Rhodes grass (*Trichloris crinita* [Lag.] Parodi) [29].

The total numbers of sites were 408 in Nebraska, 205 in Kansas, 310 in Oklahoma, and 315 in Texas. In Texas, we examined nine counties for coastal bermudagrass, nine for buffelgrass, and three for both coastal bermudagrass and buffelgrass. Mean annual rainfall ranged from 40 to 82 cm in Nebraska, 44 to 114 cm in Kansas, 78 to 119 cm in Oklahoma, and 64 to 148 cm in Texas (the coastal bermudagrass counties). The 21 southern Texas buffelgrass sites (across 12 counties) mean annual rainfall values were 50 to 85 cm. The lower number of sites for buffelgrass was due to the lower number of sites with reported buffelgrass productivity.

Statistical Approach

The approach for the first analysis was to regress mean ANPP of native plant communities against mean ANPP of alfalfa (or coastal bermudagrass). We then looked to see where each regression line crossed the 1:1 line to estimate where community productivity was as great as or greater than monoculture productivity. Next, mean coastal bermudagrass ANPP was correlated to published mean annual switchgrass ANPP from six locations in Texas [30, 31]. Alfalfa productivity was correlated to published mean annual switchgrass productivity from eight sites in the northern part of the Great Plains [32, 33] that were used in two simulation studies [34, 35]. Correspondingly, one regression was fit for switchgrass productivity as a function of alfalfa productivity. These regressions were used to estimate switchgrass productivity at all the alfalfa sites. The same was done for coastal bermudagrass productivity for the Texas sites. Finally, the reported productivity of the native communities in southern Texas was regressed against productivity of buffelgrass, in order to similarly estimate the productivities of the monoculture and diverse native community, which were similar.

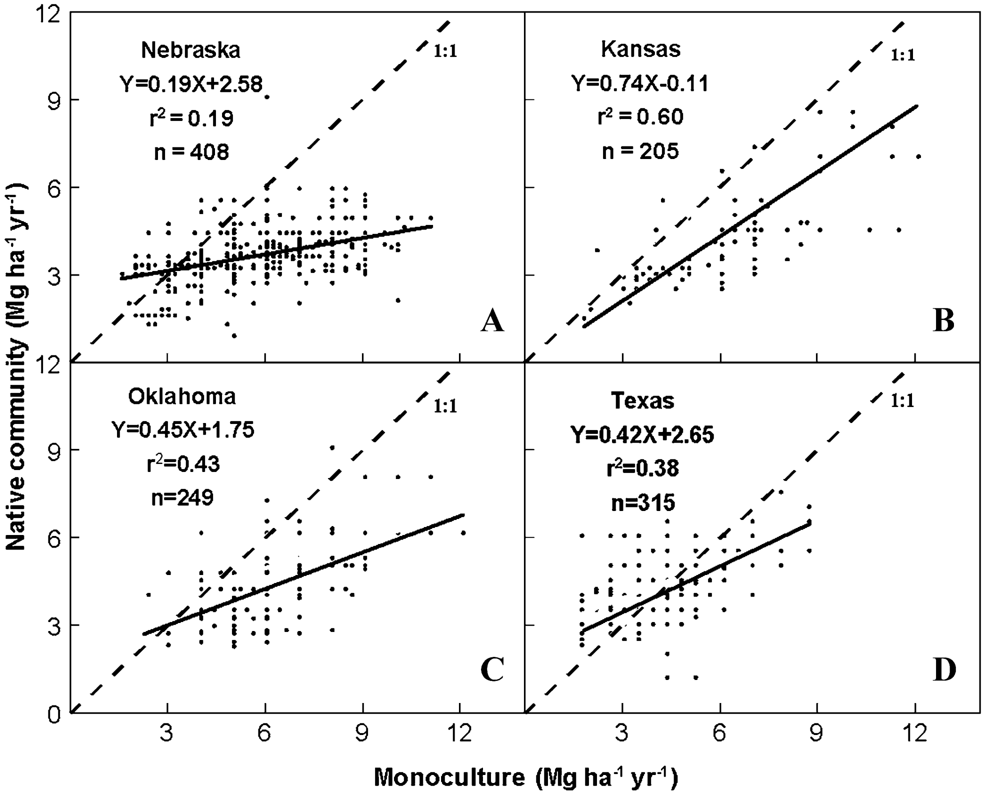
Results

In Nebraska, the regression analysis indicated that ANPP of alfalfa and native communities were comparable when alfalfa produced 3.2 Mg ha^{-1} (Fig. 2a). Only 11% of the 408 sites had native community ANPP greater than alfalfa ANPP and 2% had the same ANPP for the native community and alfalfa. Alfalfa productivity exceeded native community productivity at 87% of the sites. The mean native community ANPP was less than mean alfalfa monoculture ANPP by 30%.

In Kansas, the regression analysis showed that alfalfa ANPP exceeded native community ANPP in the range of reported values (Fig. 2b). Of 205 individual sites, 2% had native ANPP greater than alfalfa ANPP, 14% had the same ANPP for the two, and 84% had greater alfalfa ANPP. The mean native community ANPP was less than mean alfalfa monoculture ANPP by 27%.

In Oklahoma, the regression analysis showed that native community ANPP equaled monoculture alfalfa ANPP when alfalfa produced 3.0 Mg ha^{-1} (Fig. 2c). The ANPP on 13%

Fig. 2 For four states, comparison of aboveground ANPP of mixed species communities of native rangeland plants with ANPP of alfalfa (**a**, **b**, **c**) or coastal bermudagrass (**d**) monocultures as reported by USDA-NRCS



of the 249 sites was greater for native communities than alfalfa monoculture, while 2% had the same productivity for both and 85% of sites had greater ANPP for alfalfa. The mean native community ANPP was less than mean alfalfa monoculture ANPP by 25%.

In Texas, where coastal bermudagrass is the predominant monoculture planted for forate and hay, native community yields were more frequently competitive (Fig. 2d). The regression line indicated that native community ANPP was comparable with coastal bermudagrass ANPP when the latter yielded 4.6 Mg ha^{-1}. For 42% of 315 sites, ANPP was greater in the native community, while in 58% of sites, coastal bermudagrass had greater ANPP. The overall mean ANPP for the native community was 108% of the mean for coastal bermudagrass.

Switchgrass ANPP showed a linear relationship with ANPP of alfalfa and coastal bermudagrass (Fig. 3). Regressions indicated switchgrass productivity exceeded both alfalfa and coastal bermudagrass ANPP throughout the range of data. Switchgrass ANPP also exceeded native community ANPP throughout the range of reported yields, as shown by the regressions (Fig. 4a–d). These findings are in keeping with other studies, which have demonstrated switchgrass to be the species of choice in biofuel cropping systems across most of the USA [27, 36, 37].

In the more arid regions of extreme southern Texas, native grass-dominated communities were typically much more productive than managed monocultures (Fig. 5). In 81% of the sites, native community ANPP exceeded ANPP of the predominant monoculture, buffelgrass. The regression indicated that native communities had greater annual productivity at all sites where buffelgrass yielded less than 4.4 Mg ha^{-1}. Interestingly, the average coastal bermudagrass productivity values (not shown) differed from the average buffelgrass values by only 0.7%. Thus, these divergent results were not due to the monoculture plant species we selected for the region.

Discussion

Single-species systems have been adopted on vast acreages of the USA. It could be concluded that such systems were adopted in preference to mixed native plant communities because of increased productivity. Such single-species systems frequently were established on lands where overgrazing destroyed the original native plant community. Monotypic farming practices are desirable because of ease of planting and managing the system with conventional farm machinery. It is important to compare historically adjusted or “potential” native plant community ANPP with conventionally managed monoculture ANPP to account for the effects of large-scale conversion on potential ANPP of a given location and a given soil series. With the extensive USDA-NRCS databases, we were able to compare potential ANPP of mixed native species communities with conventionally managed monocultures at each site.

There are two caveats to interpreting our data. First, our analysis indicated that managed switchgrass monocultures will usually have greater ANPP than diverse native species communities or other managed monocultures. However, we would caution that one should not extrapolate beyond the range of the switchgrass data for which yields were validated, because the regression line does not account for extreme effects of droughty areas or short seasons outside the range of measured switchgrass production. A second caveat to the interpretation of these results is that different management approaches may have confounded ANPP

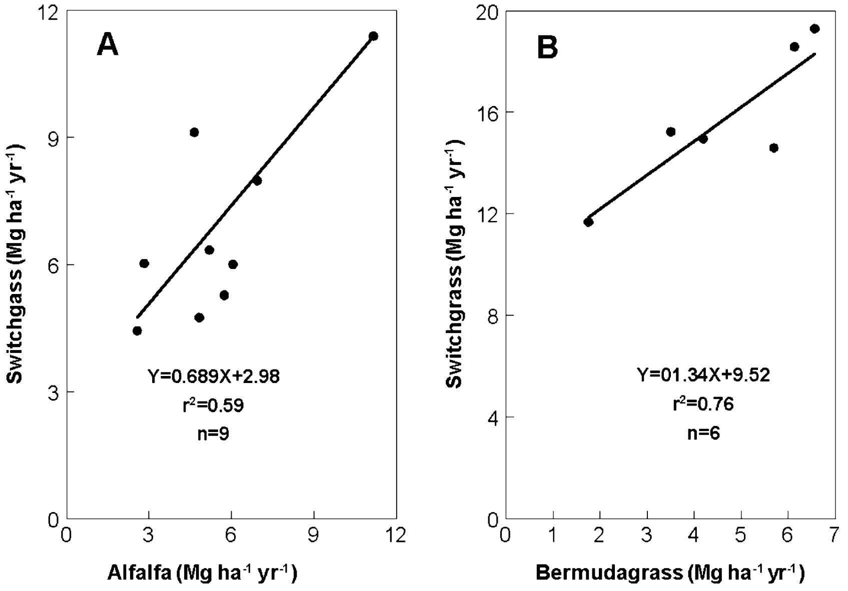


Fig. 3 Comparison of mean switchgrass aboveground ANPP with mean alfalfa ANPP in Nebraska, Kansas, and Oklahoma (**a**) ANPP and coastal bermudagrass ANPP in Texas (**b**)

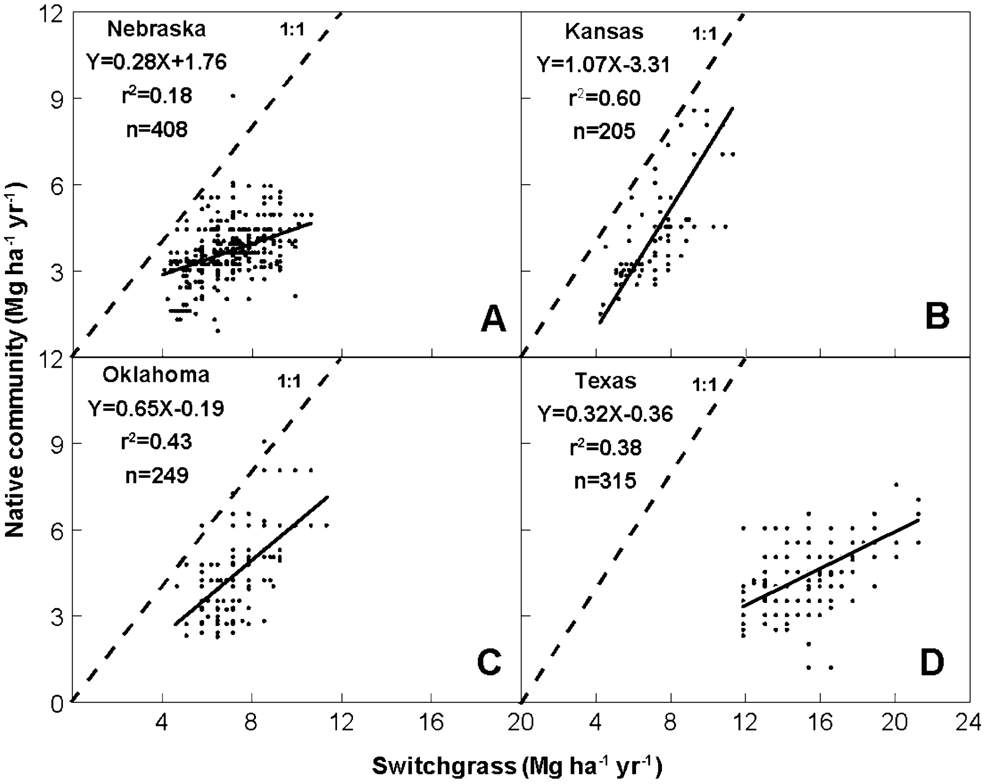


Fig. 4 Comparison of mean aboveground ANPP of diverse native plant communities with mean-managed switchgrass monoculture ANPP estimated from alfalfa monoculture yields (**a**–**c**) or from coastal bermudagrass monoculture yields (**d**) as reported by USDA-NRCS. Equations used for estimating switchgrass yields are given in Fig. 3

results. In this analysis, all monotypic systems and native communities were unirrigated; all monotypic crops were managed with site-specific fertilizer inputs to maintain annual productivity levels. However, with an agronomic approach to biomass production, the crop *will* be actively managed, even if biomass crops are grown from native species and managed with a wildlife habitat emphasis on CRP land [38, 39].

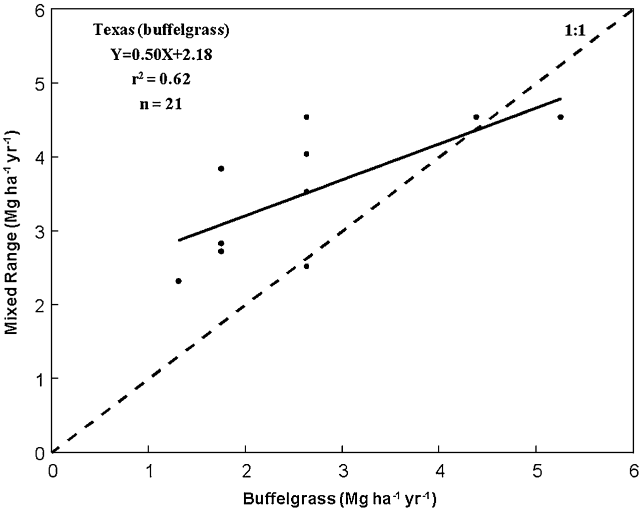


Fig. 5 For southern Texas, comparison of diverse native plant community mean ANPP with buffelgrass mean ANPP as reported by USDA-NRCS

Proponents of LIHD stress that one of the benefits of LIHD systems is the low requirement for nutrient input in their proposed production systems [9]. It is proposed that native communities comprising LIHD include nitrogen-fixing legumes, which may lower required nitrogen fertilizer inputs for yield maintenance [9]. Harvesting biomass in diverse systems may increase legume cover, which may decrease necessary fertilizer additions [40]. Arguments in support of LIHD's low nutrient requirements based on biomass production experiments in which plots were burned may not give a full accounting of carbon and nutrient dynamics in a production system [41, 42]; burning grasslands can stimulate up to 40% more growth as compared with unburned areas [43]. Even with legumes in the system, human appropriation of biomass necessarily reduces the quantity of biomass involved in ecosystem nutrient dynamics, water dynamics, carbon fluxes, food webs, and other ecosystem services [10]. Future work must address appropriate inputs required to maintain a sustainable harvest system, meeting yield and ecosystem service goals.

It has been proposed that up to 50% of CRP lands could be used for biomass production [1]. CRP lands tend to be fragile, highly erodible land, and often marginally productive, the farming of which can lead to deleterious ecosystem consequences. The 1985 US Farm Bill authorized federal payment to farmers to take these lands out of production agriculture and put them into perennial grass cover under CRP, which has led to improvements in soil quality [43–45] and wildlife habitat [8, 46]. Demand for corn (*Zea mays* L.) for ethanol has contributed to farmers putting environmentally fragile CRP land back into row-crop corn farms, despite low production potentials of CRP land and greater nutrient losses due to erosion [8]. Converting CRP land to corn ethanol production results in a carbon-debt that is not anticipated to be recovered by ethanol benefits for over 40 years [15, 47].

An alternative and likely more sustainable use proposed for 6.8 Mha of CRP land is harvesting the established perennial grass communities for biomass production [38]. High yielding perennial grasses such as switchgrass also increase soil carbon sequestration, though appropriate harvest schedules and fertilizer management must be better determined [27, 45]. Work on CRP land suggests that polycultures including switchgrass [21, 48] and switchgrass monocultures can produce sustainable amounts of biomass and supply ecosystem services with little management input while storing comparable amounts of soil carbon [36, 39]. Mean recorded yields on CRP lands are highly variable; ranges include 4.2–6.6 Mg ha^{-1} in Southern Iowa [49], 1.2–2.9 Mg ha^{-1} in South Dakota [39], and 1.7–2.2 Mg ha^{-1} in Northwestern Oklahoma [50]. Appropriately managed cutting times can extend the wildlife habitat services currently provided by CRP lands to perennial grass biofuel lands [46], but harvesting yields this low for biomass production may not make economic or ecological sense.

Annual net primary productivity (ANPP) is only one criterion for comparing monoculture versus polyculture systems in regard to biofuel cropping potentials. It has been noted that ANPP is not synonymous with ethanol yield because yield is contingent upon tissue composition. In fact, Adler et al. (2009) showed that on Northeastern US conservation grasslands, as species richness increased from 3 to 12.8 m^{-2}, ethanol yields dropped by 14% per unit plant biomass [21].

Regardless of their potential to meet human demand for cellulosic ethanol, native plant communities have a wide range of other benefits relative to monocultures, such as superior wildlife habitat and preservation of plant species diversity, including endangered plant species. In some cases, abandoned agricultural lands have reverted to diverse natural systems, while others have been placed in the CRP, such that these lands now provide important ecosystem services (carbon storage, nutrient retention, wildlife habitat, soil stability, etc.) that might be negated by conversion to biomass harvest [28]. As our data demonstrate, there are instances where these areas should be excluded from harvest, particularly when yields are very low, so that these goods and services will be preserved.

Sustainability is not synonymous with conservation [8, 16, 51, 52]. Though our results show that managed monocultures typically outyield diverse polycultures, there must be more long-term studies on sustainability of diverse biomass production systems and conservation effects of repeated harvests [6]. Production suitability is not equivalent to suitability. In other words, just because a given site will produce a given amount of biomass which, when appropriately managed, can be harvested repeatedly without a decrease in yield, does not mean that biomass appropriation for cellulosic ethanol production is the best use of that site. It is the opinion of these authors that when considering conversion of low-yielding, fragile lands to biomass production, one should pay particular mind to the effects of biomass harvest on erosion, wildlife, and other ecological services.

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Appendix 1

To illustrate how this meta-analysis was conducted, we felt it would be appropriate to demonstrate how data were collected for a representative soil in a representative county. First, the Web Soil Survey was accessed (http://websoilsurvey.nrcs.usda.gov) and initiated by clicking the green "START WSS" button on the homepage. Under the "Quick Navigation Navigate By..." toolbar on the left side of the page, click the "Soil Survey Area" tab to expand it. Select the appropriate State and County from the drop down menus. For example, choose Oklahoma and Woodward County from the list. The Soil Survey Area is now "Woodward County, Oklahoma." Click the "Set AOI" button in the upper right corner of the Soil Survey Area box. It may take a moment while the program clips the soils needed for your area of interest (AOI). The "Area of Interest Properties" will expand once the soils are clipped. It contains a "Soil Data Available from Web Soil Survey" tab, which should be expanded by default. This contains data about when the Soils Maps and Soil Data were updated for this county; in this case, Soil Maps are Version 1, March 30, 2004, and Soil Data are Version 6, September 16, 2008. The AOI is mapped on the right side of the page, with crosshatches delineating its area.

To determine yields on the soils in this AOI, click on the "Soil Data Explorer" tab at the top of the page. The default setting should have the "Suitabilities and Limitations for Use" menu already expanded. From the dropdown list, choose "Vegetative Productivity," which will expand that category. In this example, to find alfalfa yield data, click "Yields of Non-Irrigated Crops (Component)," which will open a drop down box. In this box, choose "Alfalfa hay" as the crop in the "Basic Options" dropdown. Click the "View Rating" button in the corner of the box. This will produce a table titled “Tables—Yields of Non-Irrigated Crops (Component): Alfalfa hay (Tons)—Summary By Map Unit.” When alfalfa hay production is reported for a given soil series, the average tonnage is listed in the “Rating” column. At the time of this publication, there was no reported alfalfa hay production for Delwin fine sand with 1% to 3% slopes, so this soil in this county was excluded from our comparative analysis. The next soil on the list reports alfalfa hay yields: the Carey silt loam with 1% to 3% slopes (CaB) averages 2.38 tons of alfalfa acre^{-1}.

To see the native community productivity data reported for CaB in this county, select the “Soils Reports” tab at the top of the page. On the left hand side of the page, click on the “Vegetative Productivity” tab. It will open up a dropdown menu. Choose “Rangeland Productivity and Plant Composition” from the list and click the “View Soil Report” button. This will create a table under the map titled “Report—Rangeland Productivity and Plant Composition” detailing range yields on favorable, normal, and unfavorable years. It also gives information on the ecological site description and dominant plant species. The CaB soils support loamy prairie, and miscellaneous perennial grasses make up 35% of the rangeland plants, followed by little bluestem (15%), sideoats grama (10%), and others.

References

1. Perlack RD, Wright LL, Turhollow A, Graham RL, Stokes B, Erbach DC (2005) Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, Oak Ridge
2. Tilman D, Fargione J, Wolff B, D’Antonio C, Dobson A, Howarth R et al (2001) Forecasting agriculturally driven global environmental change. Science 292:281–284
3. Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J et al (2008) Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319:1238–1240
4. Heaton EA, Dohleman FG, Long SP (2008) Meeting US biofuel goals with less land: the potential of Miscanthus. Glob Change Biol 14:2000–2014
5. Robertson GP, Dale VH, Doering OC, Hamburg SP, Melillo JM, Wander MM et al (2008) Sustainable biofuels redux. Science 322:49–50
6. Berndes G, Hoogwijk M, van der Broek R (2002) The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass Bioenerg 25:1–28
7. Hill J, Nelson E, Tilman D, Polasky S, Tiffany D (2006) Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proc Natl Acad Sci 103:11206–11210
8. Secchi S, Babcock BA (2007) “Impact of high crop prices on environmental quality: a case of Iowa and the Conservation Reserve Program” Report No. 07-WP-447, Center for Agricultural and Rural Development, Iowa State University, Ames, IA
9. Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314:1598–1600
10. Haberl H, Erb KH, Krausmann F, Gaube V, Bondeau A, Plutzar C et al (2007) Quantifying and mapping the human appropriation of net primary production of earth’s terrestrial ecosystems. Proc Natl Acad Sci 104:12942–12947
11. Landis DA, Gardiner MA, van der Werf W, Swinton SM (2008) Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proc Natl Acad Sci 105:20552–20557
12. Field CB, Campbell JE, Lobell DB (2007) Biomass energy: the scale of the potential resources. Trends Ecol Evol 23:65–72
13. Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR et al (2005) Global consequences of land use. Science 309:570–574
14. Schmer MR, Vogel KP, Mitchell RB, Perrin RK (2008) Net energy of cellulosic ethanol from switchgrass. Proc Natl Acad Sci 105:464–469
15. Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P (2008) Land clearing and the biofuel carbon debt. Science 319:1235–1238
16. Campbell JE, Lobell DB, Genova RC, Field CB (2008) The global potential of bioenergy on abandoned agriculture lands. Envir Sci Tech 42:5791–5794
17. Willms WD, Entz T, Beck R, Hao X (2009) Do introduced grasses improve forage production on the northern mixed prairie? Rangeland Ecol Manag 62:53–59
18. Hooper DU, Chapin FS III, Ewel JJ, Hector A, Inchausti P, Lavorel S et al (2005) ESA report: effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Eco Monographs 75:3–35
19. Grace JB, Anderson TM, Smith MD, Seabloom E, Andelman SJ, Meche G et al (2007) Does species diversity limit productivity in natural grassland communities? Eco Lett 10:680–689
20. Adler PR, Sanderson MA, Goslee SC (2004) Management and composition of lands in the Northeastern United States. In Barnes TG, Kiesel LR (eds) Proc. Fourth Eastern Native Grass Symposium 2004 Oct 3-6. University of Kentucky, Department of Forestry, Lexington, KY, pp. 187–200, http://www.uky.edu/Ag/Forestry/TBarnes/Assets/Proceeding.pdf
21. Adler PR, Sanderson MA, Weimer PJ, Vogel KP (2009) Plant species composition and biofuel yields of conservation grasslands. Eco App 19:2202–2209
22. Knapp AK, Fay PA, Blair JM, Collins SL, Smith MD, Carlisle JD et al (2002) Rainfall variability, carbon cycling, and plant species diversity in a mesic grassland. Science 298:2202–2205
23. Foley JA, Monfreda C, Ramankutty N, Zaks D (2007) Our share of the planetary pie. Proc Natl Acad Sci 104:12585–12586
24. Matson PA, Vitousek PM (2006) Agricultural intensification: will land spared from farming be land spared for nature? Conserv Biol 20:709–710
25. Johnson JMF, Allmaras RR, Reicosky DC (2006) Estimating source carbon from crop residues, roots, and rhizodeposits using the national grain-yield database. Agron J 98:622–636
26. Ceotto E (2008) Grasslands for bioenergy production. A review. Agron Sustain Dev 28:47–55
27. Walsh ME, de la Torre Ugarte DG, Shapouri H, Slinsky SP (2003) Bioenergy crop production in the United States. Environ Res Econ 24:313–333
28. Sanderson MA, Adler PR (2008) Perennial forages as second generation bioenergy crops. Int J Mol Sci 9:768–788
29. USDA-NRCS Web Soil Survey; http://websoilsurvey.nrcs.usda.gov
30. Kiniry JR, Sanderson MA, Williams JR, Tischler CR, Hussey MA, Ocumpaugh WR et al (1996) Simulating Alamo switchgrass with the ALMANAC model. Agron J 88:602–606
31. Kiniry JR, Cassida KA, Hussey MA, Muir JP, Ocumpaugh WR, Read JC et al (2005) Switchgrass simulation by the ALMANAC model at diverse sites in the southern U.S. Biomass Bioenerg 29:419–425

32. Casler MD, Vogel KP, Taliaferro CM, Wynia RL (2004) Latitudinal adaptation of switchgrass populations. Crop Sci 44:293–303
33. Schmer MR, Vogel KP, Mitchell RB, Moser LE, Eskridge KM, Perrin RK (2006) Establishment stand thresholds for switchgrass grown as a bioenergy crop. Crop Sci 46:157–161
34. Kiniry JR, Schmer MR, Vogel KP, Mitchell RB (2008) Switchgrass biomass simulation at diverse sites in the Northern Great Plains of the U.S. BioEnergy Res 1:259–264
35. Kiniry JR, Lynd L, Greene N, Johnson M-VV, Casler M, Laser MS (2009) Biofuels and water use: comparison of maize and switchgrass and general perspectives. In: Wright JH, Evans DA (eds) New research in biofuels. Nova Science Publisher, Inc, New York
36. McLaughlin SB, de la Torre Ugarte DG, Garten CT Jr, Lynd LR, Sanderson MA, Tolbert VR et al (2002) High-value renewable energy from prairie grasses. Envir Sci Tech 36:2122–2129
37. Gonzalez-Hernadez JL, Sarath G, Stein JM, Owens V, Gedye K, Boe A (2009) A multiple species approach to biomass production from native herbaceous perennial feedstocks. Plant 45:267–281
38. Walsh ME, De La Torre Ugarte DG, Shapouri I, Slinsky SP (2003) Bioenergy crop production in the United States. Environ Res Econ 24:313–333
39. Mulkey VR, Owen VN, Lee DK (2006) Management of switchgrass-dominated conservation reserve program lands for biomass production in South Dakota. Crop Sci 46:712–720
40. Jewett JG, Sheaffer CC, Moon RD, Martin NP, Barnes DK, Breitbach DD et al (1996) A survey of CRP land in Minnesota. 1. legume and grass persistence. J Prod Agric 9:528–534
41. Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels and low-input high-diversity grassland biomass. Science Supporting Online Material. www.sciencemag.org/cgi/content/full/314/5805/1598/DCI
42. Russelle MP, Morey RV, Baker JM, Porter PM, Jung HGH (2007) Comment on “carbon negative biofuels from low input high diversity grassland biomass”. Science 316:1567b
43. Baer SG, Kitchen DJ, Blair JM, Rice CW (2002) Changes in ecosystem structure and function along a chronosequence of restored grasslands. Eco App 12:1688–1701
44. Huang X, Skidmore EL, Tibke GL (2002) Soil quality of two Kansas soils as influenced by the Conservation Reserve Program. J Soil Water Conserv 57:344–350
45. Lee DK, Owens VN, Doolittle JJ (2007) Switchgrass and soil carbon sequestration response to ammonium nitrate, manure, and harvest frequency on Conservation Reserve Program Land. Agron J 99:462–468
46. Fargione JE, Cooper TR, Flaspohler DJ, Hill J, Lehman C, McCoy T et al (2009) Bioenergy and wildlife: threats and opportunities for grassland conservation. BioScience 59:767–777
47. Piñeiro G, Jobbágy EG, Baker J, Murray BC, Jackson RB (2009) Set-asides can be better climate investment than corn ethanol. Eco App 19:277–282
48. Mulkey VR, Owen VN, Lee DK (2008) Management of warm-season grass mixtures for biomass production in South Dakota, USA. Bioresource Technol 99:609–617
49. Florine SE, Moore KJ, Fales SL, White TA, Burras CL (2006) Yield and composition of herbaceious biomass harvested from naturalized grassland in southern Iowa. Biomass Bioenerg 30:522–528
50. Venuto BC, Daniel JA (2010) Biomass feedstock harvest from conservation reserve program land in Northwestern Oklahoma. Crop Sci 50:737–743
51. Struhsaker TT (1998) A biologist’s perspective on the role of sustainable harvest in conservation. Conserv Biol 12:930–932
52. Milder JC, McNeely JA, Shames SA, Scherr SJ (2008) Biofuels and ecoagriculture: can energy production enhance landscape-scale ecosystem conservation and rural livelihoods? Int J Agric Sustain 6:105–121