Proceedings of the Integrated Crop Management Conference
Proceedings of the 25th Annual Integrated Crop Management Conference

Dec 4th, 12:00 AM

Producing food, feed and energy: How can agriculture do it all?

Emily Heaton
Iowa State University, heaton@iastate.edu

Lisa Schulte-Moore
Iowa State University, lschulte@iastate.edu

Matt Helmers
Iowa State University, mhelmers@iastate.edu

Matt Liebman
Iowa State University, mliebman@iastate.edu

Ferman Milster
University of Iowa

Heaton, Emily; Schulte-Moore, Lisa; Helmers, Matt; Liebman, Matt; and Milster, Ferman, "Producing food, feed and energy: How can agriculture do it all?" (2013). *Proceedings of the Integrated Crop Management Conference*. 7.
https://lib.dr.iastate.edu/icm/2013/proceedings/7

Producing food, feed and energy: How can agriculture do it all?[1]

Emily Heaton, assistant professor, Agronomy, Iowa State University; Lisa Schulte-Moore, associate professor, Natural Resource Ecology and Management, Iowa State University; Matt Helmers, associate professor, Agricultural and Biosystems Engineering, Iowa State University; Matt Liebman, professor, Agronomy, Iowa State University; Ferman Milster, Principal Engineer – Renewables, Office of Sustainability, University of Iowa

Abstract

Sustainable intensification of agricultural systems has been suggested – in addition to reducing waste and changing consumption habits – as a way to increase food, feed, fuel, and fiber security in the 21st century. Here we describe three primary strategies of agricultural intensification – conventional intensification, temporal intensification, and spatial intensification – and how they can be used to manage and integrate food and second-generation (2G) crop portfolios. While each strategy has individual merits, combining them to meet case-specific targets may achieve optimum results. Multiple experiments and examples from Iowa, USA illustrate the potential of combining these approaches for agroecological intensification that can provide ecosystem services while maintaining or increasing economic output, thus striking a balance between 'land sparing' and 'land sharing'. Management strategies will vary by the types of markets available, e.g., food, fuel and/or ecosystem services, and the scale of markets supplied, e.g., small heat and power vs. large cellulosic ethanol. Future research should holistically and methodologically evaluate the trade-offs between different management strategies.

Introduction

Integrating food and second-generation (2G) biofuel crop production, while maintaining or enhancing the health of human and natural systems, is a 'grand challenge' of the 21st century (Council, 2009, Tilman et al., 2009). In the next few decades, the global human population is expected to reach 9 billion and food demand to grow by 70 to 100% (Tilman et al., 2011). More calories can be made available by shifting to plant-based diets, increasing efficiency of food distribution, and reducing the 30 to 50% of food that is annually thrown away or lost, but more food will still be needed (Foley et al., 2011, Gustavsson et al., 2011). Concomitantly, demand for biofuels and biopower is growing (International Energy Agency, 2013). The stage appears to be set, then, for a conflict between food and fuel production; it is estimated that meeting current biofuel targets in the USA could take substantial land area from current food and feed crops. For example, the USA already uses roughly 40% of annual maize (*Zea mays* L.) production for ethanol (USDA, 2013b); and, globally, 15% of cereal and plant oils plus 30% of sugarcane (*Saccharum officinarum* L.) production are expected to be marketed for biofuels until the year 2020 (Tscharntke et al., 2012).

While demand for agricultural outputs grows, the industrial-style agriculture practiced so commonly in the developed world is already stressing the ability of ecosystems to provide provisioning, regulating, and cultural services critically needed for a healthy society (Tscharntke et al., 2012). Global climate change will exacerbate existing stresses and jeopardize agriculture's ability to meet societal demands for food, feed, fuel, and fiber (Walthall et al., 2012). Such alarming projections highlight the pressing need to balance and integrate food and fuel production in a way that protects the natural resources on which life depends.

From an operational perspective, farmers and land managers have the most direct impact on agricultural land use. This paper lays out management strategies they might employ to integrate production of food/feed and 2G energy crops, recognizing that economic, social, and policy drivers beyond the scope of this paper influence actual decision-making. We describe land management strategies using examples from research and demonstration projects in Iowa, USA and posit that such strategies can be used to achieve multiple societal goals. Detailed examination and rigorous

---

[1] *Proceedings article adapted from: Heaton E.A., Schulte L.A, Berti M., Langeveld H., Zegada-Lizarazu W., Parrish D. & Monti, A. (2013) Integrating Food and Fuel: How to Manage a 2G Crop Portfolio. BioFPR Article first published online: 29 JUL 2013, DOI: 10.1002/bbb.1429*

methodological comparisons against established baselines will be necessary, however, to evaluate comparative trade-offs between strategies. Our focus here is predominantly on the developed world.

The issue of land tenure underlies all recommendations for agricultural land management strategies. In the USA, roughly 40% of farmland is rented (Nickerson et al., 2012). Renters operate on annual timelines and rarely have the opportunity to make long-term decisions about land management. The best interest of land owners would be ensured, however, if farmland were managed using sustainable farming methods, since farmland value is positively correlated with soil quality (Nickerson et al., 2012).

The methods used to manage any crop portfolio should be tailored to each farming operation, but successfully integrating food and fuel production will likely mean intensification of existing agriculture – both in land area and in management requirements. The USA and Europe Union (EU) both have land reserve programs retiring degraded cropped land for conservation benefits. As the price of grain increases and federal budgets contract, much land is coming out of those reserve programs and being put back into agriculture. In the USA, for example, enrollment in the Conservation Reserve Program (CRP) dropped from 12.7 Mha in 2010 to 11.0 Mha in 2012, with roughly another million ha poised to come out in 2013 (USDA, 2013a). Using degraded agricultural land and changing practices on current farmland are both features of 'sustainable intensification' strategies proposed to increase agricultural productivity (Gomiero et al., 2011). In what follows, we consider three types of agricultural intensification – conventional, temporal, and spatial intensification – and then describe their deployment in examples from Iowa, USA.

Sustainable intensification strategies for integrating food and 2G crops

The concept of sustainable intensification depends in part on location, as reflected in the ongoing debate of land sharing and land sparing (Anderson-Teixeira et al., 2012, Phalan et al., 2011). In the developing world, increasing the land area used for farming would likely come from clearing native landscapes and have negative environmental impacts, leading some to conclude that land should be 'spared' for conservation, and agriculture improved on existing farmland (Knoke et al., 2012, Tscharntke et al., 2012). Indeed, considerable opportunity exists for increasing productivity, particularly in parts of South America, West Africa, and Eastern Europe (Foley et al., 2011). By contrast, in the developed world, 'sharing' the already developed industrial cropland (or degraded former farmland of the aforementioned land reserve programs) with 2G energy crops could actually improve ecosystem functions (Gelfand et al., 2013, Schulte et al., 2006, Tilman et al., 2009). Currently, however, ecosystem services are not directly valued in the marketplace, and farmers' management decisions are driven largely by income derived from grain sales and government programs.

In the USA and EU, food and energy markets are heavily regulated, historically leading to surpluses of grain crops that would be unlikely in a free-market system. Subsidies and mandates encourage production of some crops, e.g., maize, soybean [(*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.), and canola (*Brassica napus* L.); and farmers have become accustomed to those cropping systems. At a basic level, however, land managers choose cropping systems and how to deploy them by considering the constraints of available resources, natural and otherwise, and match those constraints with desired system goals, such as: producing food, feed, fiber, and/or fuel; deriving an income; maintaining quality of life; and conserving soil, water, air, and biodiversity (Fig. 1). Reimagining agriculture to integrate food and 2G fuel allows us to freshly consider management options from a 'first principles' perspective. It is through this lens that we now examine sustainable intensification strategies.

Conventional intensification

Conventional intensification aims to close the gap between theoretical and actual crop yield in traditional commodity systems and is the most commercially advanced strategy to integrate food and 2G fuel systems. Maize stover is already being harvested for use in cellulosic ethanol biorefineries in the USA, for example, while switchgrass (*Panicum virgatum* L.) and other perennial grasses are in demonstration for dual-use as forage and bioenergy (DuPont, 2012, Poet, 2012).

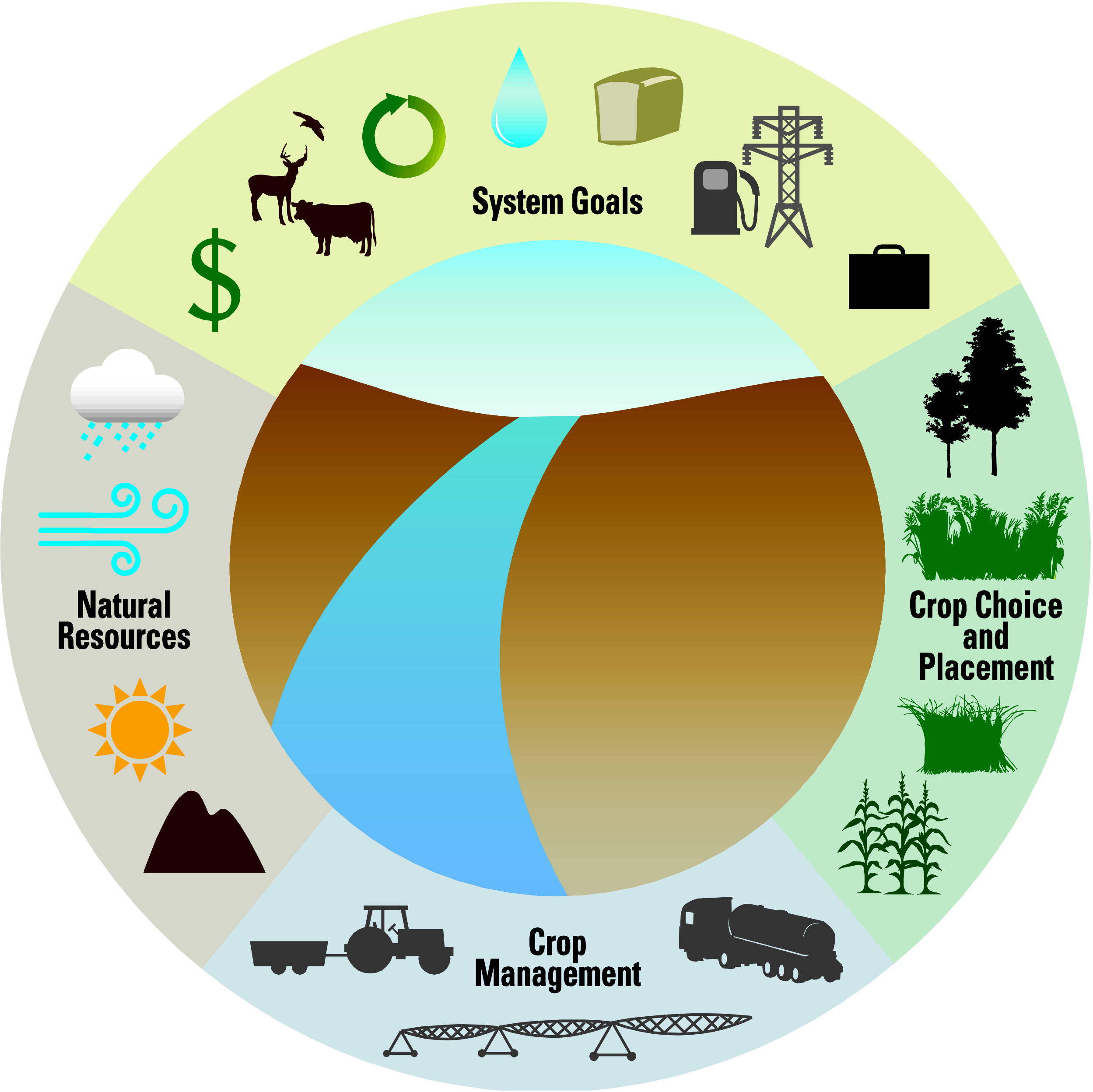

Figure 1. Simplified depiction of landscape management options, i.e., perennial vs. annual crops, tillage vs. no-tillage, conventional vs. organic pest management, that can be targeted to meet desired ecosystem functions, e.g., food and fuel provisioning, water quality protection, soil improvement, wildlife habitat, given natural resource availability. Land managers must match the resources they have available to meet economic, ecological and social goals.

Conventional intensification typically connotes deployment of advanced genetics, inputs, and infrastructure targeted at yield-limiting traits so that a crop lacks nothing during its growth cycle (Brussaard et al., 2010). In the scientific literature, conventional intensification focuses on the developing world, where major gains could be realized by exploiting technologies commonly used in the developed world, e.g., Godfray et al.(2010). By contrast in the developed world, where farmers can afford new technologies, major agri-businesses are working to achieve still higher yields, as illustrated by the campaign for "300 bu. maize" (approximately 19 Mg ha-1) in the USA (Schill, 2007). Conventional intensification tends to use high inputs (energy, fertilizer, irrigation, and pesticides) and advanced technology (larger equipment) to homogenize crop growth environments and reduce management time per unit land area. This high-input approach, however, has been causally linked to increased agrochemical pollution, soil erosion, greenhouse gas emissions, and decreased biodiversity, as reviewed in Gomiero et al.(2011).

Water, fertilizer, and fossil fuel scarcity have led to a renewed focus on efficiency in conventional intensification. More recently, with the widespread availability of global positioning system (GPS) technology, conventional intensification has focused on controlling spatial variability in fields using site-specific management and variable-rate application of chemicals and seed, i.e., precision agriculture (Bramley, 2009, Edan et al., 2009). More than 30% of US farmers have adopted GPS or variable-rate technologies (Schimmelpfennig & Ebel, 2011) with increased profits over non-adopters (Bullock et al., 2009). New crop genotypes are bred for stress tolerance in addition to input response, and precision agriculture, in combination with a growing awareness of unintended environmental degradation, should enable increased agricultural productivity with reduced negative externalities (Godfray et al., 2010).

Temporal intensification

Temporal intensification here simply means increasing the number of crops grown in a given period of time. Using more of the growing season by including cover crops, double- and relay-crops (a relay-crop is here defined as the seeding of a second crop before harvesting the first) can integrate food, feed, and energy crops without using additional land. At the beginning and end of each season in conventional annual food cropping systems, there is often room to add another crop without using additional land (Fig. 2). These combined systems have been shown to work quite well even in areas with short growing seasons (Goff et al., 2010, Heggenstaller et al., 2008).

The following are four ways of achieving temporal intensification in temperate cropping systems. The strategies detailed below would increase production of 2G crops without preempting land used for food, by instead incorporating into it.

In a first example, cover crops can be planted before a dual-use crop such as forage sorghum [*Sorghum bicolor* L. Moench], which can be used as animal feed or for 2G energy (Berti et al., 2012). In a 2G cropping system, cover crops, or over-wintering crops, can provide additional biomass that supplements the primary crop (Fig. 2). Cover crops are already recognized to have many benefits in traditional cropping systems such as preventing soil erosion, taking up excess N, providing habitat for beneficial insects, reducing soil compaction, and increasing water infiltration (Fouli et al., 2012, Munkholm et al., 2013). Cereal crops typically require relatively high fertilizer inputs, (Goff et al., 2010, Heggenstaller et al., 2008) but legume cover crops can add N to the system, reducing the N application needed for the following crop. In a recent study, yields of three annual dual-use bioenergy crops, maize, sweet sorghum (*Sorghum bicolor* L), and forage sorghum, were 2 to 3 Mg ha-1 higher when following a legume cover crop (Berti et al., 2012), leading to the conclusion that the additional N fixed by the legume cover crops enhanced the biomass yield in these bioenergy crops.

A second example of temporal intensification is use of winter-annual oilseeds for 2G energy. Crops under development, such as camelina (*Camelina sativa* L.) and field pennycress (*Thlaspi arvense* L.), can be used as a double- or relay-crop with forage sorghum, soybean, or sunflower (*Helianthus annuus* L.) (Berti et al., 2012, Gesch & Archer, 2013, Johnson et al., 2009). Winter-annual oilseeds can be seeded in the fall and mature early enough in the spring to allow the seeding of a relay- or double-crop after the oilseed harvest (Fig. 3).

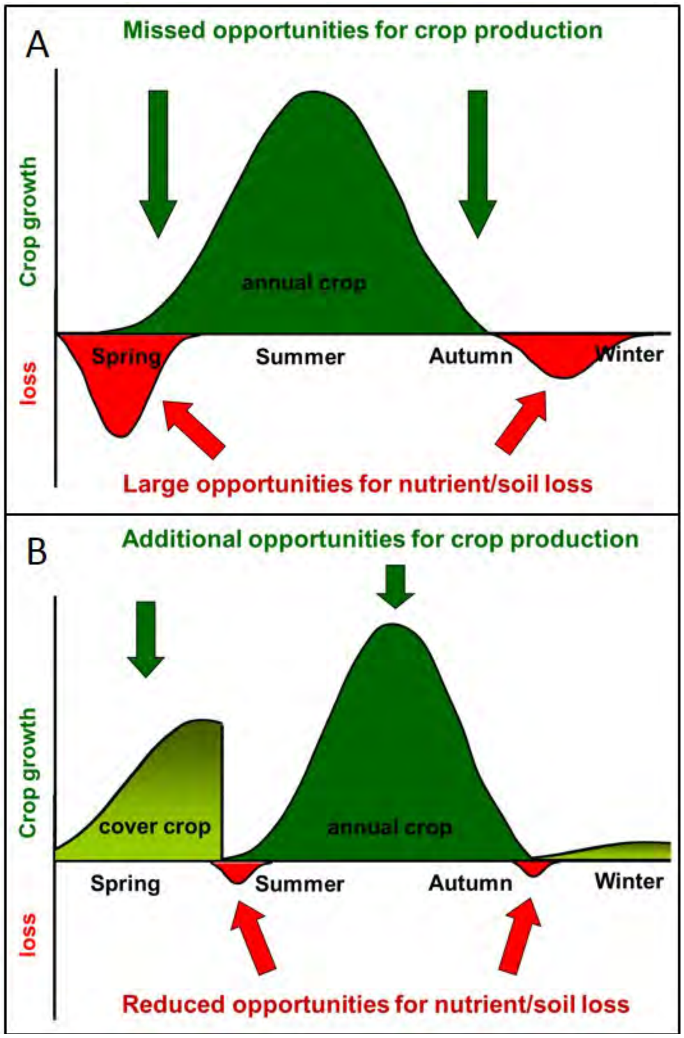

Figure 2. Temporal intensification of an annual grain crop system through addition of a winter cover crop provides additional opportunity for biomass accumulation while reducing opportunity for soil and nutrient loss from the system. Adapted from Heggenstaller et al. (2008).

A third example of temporal intensification is to sow a cover crop after a cereal crop harvest, followed by an energy crop planting the next season (Berti et al., 2012). Annual lignocellulosic crops, such as forage sorghum, can be easily incorporated into food, feed, and fiber cropping systems in some locales. Forage sorghum can be grown after a winter oilseed crop, has greater water- and N-use efficiency than maize or wheat, and is tolerant of moderately saline soils (Goff et al., 2010).

Finally, using cover crops or intercropping legume crops in the first year of dedicated perennial energy crops such as switchgrass, reed canary grass (*Phalaris arundinacea* L.), or miscanthus (*Miscanthus* × *giganteus*) could provide N that can help the perennial crop reach its potential productivity faster (Xu et al., 2008, Xu et al., 2010) – as well as potential biomass for conversion to fuel.

Figure 3. An example of temporal intensification through relay-cropping. Forage sorghum is seeded in relay into the winter-annual camelina. The sorghum will begin growing after the camelina is harvested, so although the crops are in the field at the same time, they don't compete for resources. Photo credit: Dr. Adnan Orak.

Spatial intensification

Our consideration of spatial intensification of agricultural systems is based in part on the compartmental approach (Odum, 1969) as applied in Knoke et al. (2012) and aims to strike a balance between natural and managed ecosystems (Fig. 4; Foley et al. (2005). Spatial intensification involves responding to landscape structure through strategic placement of cultivated and natural systems, such that overall ecosystem function is increased across the mosaic (Brussaard et al., 2010, Foley et al., 2005, Tscharntke et al., 2012). In practice at the farm scale, it is simply matching crops with the landscape position best suited to their growth, e.g., flood-tolerant trees in riparian areas, drought-tolerant grasses on sideslopes, and annual grain crops on flat, fertile areas (Fig. 1), such that provisioning and regulating ecosystem services are best provided.

Spatial intensification is inherently a top-down approach to agricultural intensification and as such, may not be socially acceptable in some areas, but its strategic and holistic nature enables multi-functional agro-ecosystems (Knoke et al., 2012). In some areas, farmers may not own enough of the landscape to make management decisions at the scale needed for spatial intensification; but, in the USA, fewer people are now managing more of the land, as modern farms grow larger (Atwell et al., 2010, MacDonald, 2011).

Incorporating 2G energy crops into food/feed crop systems could ameliorate the damage caused by annual grain crop systems while still producing farm income (Atwell et al., 2011, Schulte et al., 2006). Specifically, targeting perennial plants to sensitive areas of the landscape can provide disproportionate returns in ecosystem services including pest control (Thomson & Hoffmann, 2011), wildlife habitat (Rupp et al., 2012), water quality (Helmers et al., 2012), soil quality, and carbon sequestration (Bonin & Lal, in press, Lal et al., 2011). Specific examples of sustainable spatial, temporal, and conventional intensification in Iowa, USA follow.

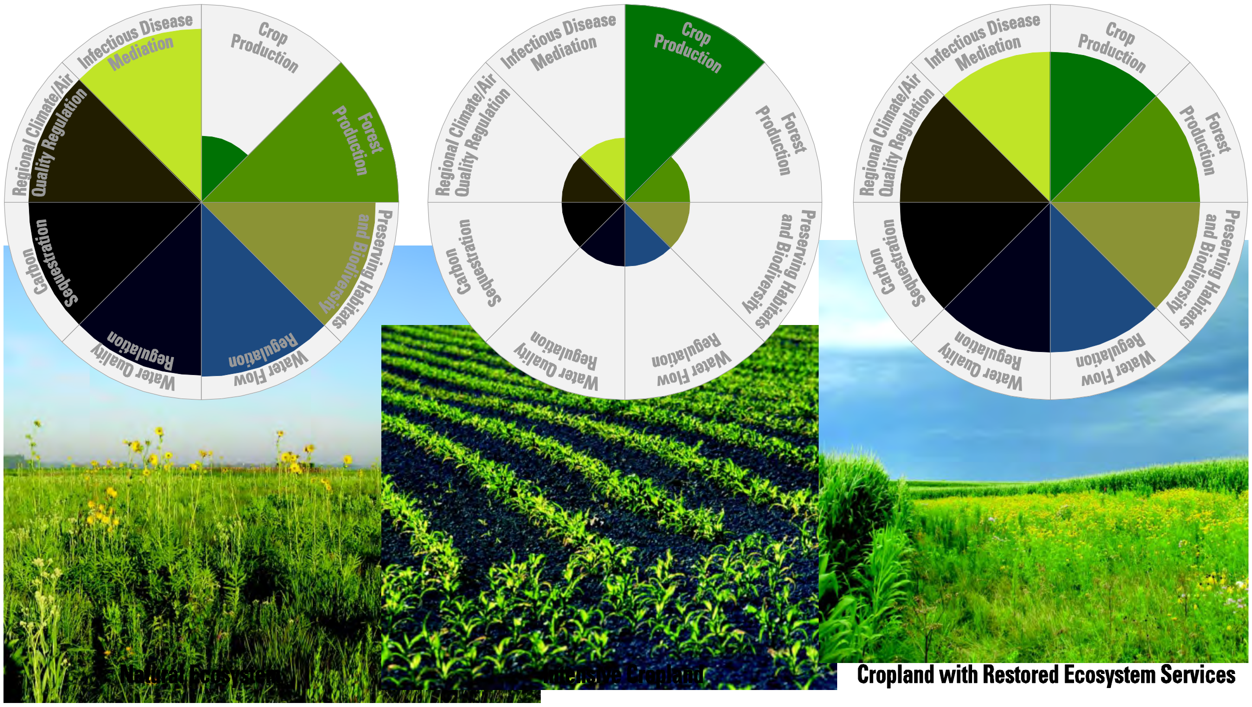

Figure 4. Land sparing and land sharing agricultural intensification strategies provide varying ecosystem functions. The left and middle panels show the extremes of the land sparing strategy, while the right panel uses a combination of the strategies in an 'agroecological intensification' approach, e.g., Tscharntke et al.,(2012) to provide multiple ecosystem functions. Adapted from (Foley et al., 2005).

Four examples of sustainably intensifying and integrating food and 2G fuel production

Cellulosic Ethanol Facility in Iowa, USA – conventional and spatial intensification

DuPont has broken ground on a $200 million biorefinery in Nevada, Iowa, USA, expected to be completed in mid-2014. The facility will be among the world's first and largest commercial-scale cellulosic biorefineries, offering the opportunity to continue to derive food, feed, and fuel from maize, but from different portions of the plant. Representing an example of conventional intensification, DuPont will use advanced harvesting and logistics technology to collect maize stover within an approximately 50-km radius around the facility in the heart of the US Maize Belt (Fig. 5). Precision agriculture and georeferencing techniques developed in collaboration with local universities and farmers will be used to ensure the amount of stover removed does not exceed targeted limits. Because targeted limits vary according to topography and measured grain yield, this project is also an example of spatial intensification.

Over 500 local farmers have contracted to gather, store, and deliver over 375,000 Mg y-1 of dry maize stover to the facility, reducing waste and providing additional benefit for farmers. Some say they have seen positive effects of maize stover removal on grain yields the following year (DuPont, 2012). Such a yield increase may be because of possible inhibitory effects of maize stover in continuous maize cropping systems. Leftover maize stover may interfere with planting, compete for N in the soil, and harbor damaging insects, pathogens, and pests. Research is underway at the site to assess short-term benefits of maize stover removal, as well as long-term tradeoffs associated with removal and use of maize stover for biofuel.

Figure 5. DuPont's Nevada Cellulosic Ethanol Facility near Nevada, Iowa, USA, is an example of conventional and spatial intensification. The 114 million L facility uses maize residue from farms within a 50 km radius, while the grain is used for food, feed and first-generation ethanol. Photo credit: DuPont Industrial Biosciences.

DuPont says its new facility will annually generate 114 million L of cellulosic ethanol from maize stover residues, and the US Department of Energy estimates the process for producing cellulosic ethanol will reduce greenhouse gas emissions by 85% compared to fossil fuel use of the same volume. DuPont further estimates that the facility will produce 60 full-time jobs, and an additional 150 people will help seasonally with the collection, stacking, transporting, and storage of the stover feedstock.

While the 114 million L of biofuel that the facility expects to produce is only a fraction of the 530 billion L of gasoline the USA consumes annually, the facility represents an advancement for sustainable energy production. Regional businesses and academic institutions have expressed interest in replacing portions of their coal-fired operations with biofuel from the DuPont refinery. A local maize-grain ethanol facility, Lincolnway Energy, has expressed interest in using byproducts from the cellulosic conversion process to replace the coal they currently use for heat and power, thus improving the fossil fuel "footprint" of grain ethanol production. Currently coal mined over 1000 km away in the western USA is brought to the plant by train.

The STRIPS Project - spatial intensification

"Prairie strips" – contour buffer and filter strips composed of diverse, native, and/or perennial plants within row-cropped agricultural fields – provide a means of more strategically integrating food, feed, fuel, and ecosystem service production. In this integrated system, row crops used primarily for food or feed comprise the majority (80 to 90%) of the agricultural field, while prairie vegetation provides ecosystem service benefits and can also be harvested for fuel production. The attributes, function, costs, and benefits of this novel practice are currently under investigation at the Strategic Trials of Row crops Integrated with Prairie Strips (STRIPS) research and demonstration site in Iowa, USA (Fig. 6; http://prairiestrips.org).

Figure 6. Scientists evaluate the impact of strategically locating strips of native prairie within a conventional maize/soy cropping system on plant and animal biodiversity at the STRIPS project in central Iowa. Photo credit: Meghann Jarchow.

Researchers are assessing the impacts of the amount and location of prairie strips within catchments on a suite of agronomic and ecological outputs. The project has shown thus far that prairie strips provide ecosystem service benefits in amounts disproportionate to their spatial extent, providing support for a spatially intensified approach. For example, catchments with just 10% of their area placed in prairie strips had a 95% reduction in sediment transport, 90% reduction in P and total N transport, and 60% reduced surface water flow compared to catchments entirely in row-crop production (Helmers et al., 2012, Hernandez-Santana et al., 2013, Zhou et al., 2010). Prairie strips also provide habitat that appears beneficial for the conservation of native communities—including plants, birds, insect pollinators, and natural enemies of pests (Fig. 6) (Cox Ohde, 2012, Hirsh et al., 2013, MacDonald, 2012). The prairie strips achieve these benefits without negatively impacting the yield of adjacent row crops or creating weed problems (Hirsh et al., 2013). To maintain a viable prairie flora, strips were burned or harvested outside the growing season. If harvested, the plant material can be used as a feedstock for 2G bioenergy production. Harvested prairie strips at the STRIPS sites have produced an average of 7.2 Mg ha-1 y-1, a yield comparable to switchgrass monocultures in the region.

The strips are cost-effective; the 10% prairie strips design has thus far produced the same level of benefits as the 20% strips design. Compared to other, more widely used conservation practices, the costs associated with establishing and managing prairie strips is 60% lower than that of terracing and 20% lower than developing nutrient-removal wetlands (Tyndall et al., 2013). Prairies strips are an easy and flexible option for farmers, because they need very little maintenance once established and, unlike terraces or wetlands, they can be easily navigated by large equipment. While we expect prairie strips would provide substantial benefit in terms of habitat provision on all portions of the agricultural land base, the STRIPS team especially recommends the practice for undulating agricultural lands with slopes of 4 to 10%.

A decade following initial scientific team discussions that led to the STRIPS experiment, prairie strips are being adopted by farmers and land managers across Iowa, in the heart of the US maize belt. Attributes contributing to adoption include the development of prairie strips as an efficient way to meet multiple ecosystem service goals through spatially strategic incorporation of the practice into existing food and feed production systems. Prairie strips could provide the added benefit of fuel through biomass production, should a robust bioenergy market develop in the region.

Landscape Biomass Project - conventional, temporal and spatial intensification

The Landscape Biomass Project (www.nrem.iastate.edu/landscapebiomass) is a long-term, transdisciplinary study in central Iowa, USA. Its aim is to develop a portfolio of integrated food, feed, and fuel crops that together – through the combined approach of conventional, temporal, and spatial intensification – are productive, profitable, and also produce ecosystem services. Building on experience from the STRIPS project, the Landscape Biomass Project is evaluating the ability of several alternative cropping systems that have a direct market value today, unlike the prairie strips, and that can be strategically deployed across the landscape to provide marketable products as well as ecosystem services. The cropping systems under investigation were chosen because of their potential to provide: 1) superior feed and biomass yields (triticale (*Triticosecale x Whit*.) and/or sorghum); 2) some food, feed, and biomass yield while mitigating some environmental impacts of traditional crops (maize-soy-triticale/soy and maize-switchgrass); or 3) some short-term biomass yield and superior long-term yield while producing a broad suite of ecosystem services (triticale-trees). As crop performance is strongly tied to site factors, biomass cropping systems are being evaluated across a series of landscape positions (Fig. 7).

Initial research findings of the on-going studies have documented variation in baseline soil conditions along a topographic gradient (Ontl et al., 2013); and various crops have been established across the suite of environmental conditions. These offer the opportunity to produce crops across the entire landscape gradient (Gunther, 2011). On-going investigation is assessing the amount of variation in grain yields, biomass yields, soil moisture, and soil water quality among cropping systems and landscape positions. Also being assessed are farmers' and land managers' ability to profitably manage double-crops in the region. In time, we expect this knowledge to provide a stronger basis for a temporally and spatially targeted approach to managing land for food, feed, and fuel production while maintaining or improving other ecosystem services.

A question of scale

The production of dedicated crops for 2G biofuels will likely gravitate to large-scale farming systems with the most suitable combination of diversification (because of the flexibility and risk reduction diversity provides) and lower inputs (because of the savings in cost and resources that lowered inputs provide) (Tilman et al., 2006). The amount of feedstock required by a processing plant will vary depending on the chosen conversion pathway; demand by the biorefinery will establish the demand for land dedicated to feedstock production (Fig. 8).

Clearly, this is a chicken-and-egg consideration; biorefineries requiring huge amounts of feedstock will not be built in an area where sufficient land is not available within a reasonable transport distance. Thus, in portions of the USA where land parcels are small, for example, small-and medium-scale combustion plants that co-fire biomass are a valuable alternative to large-scale biorefineries. Studies in the UK suggest that the best co-fired plant size is about 50 MW (Van den Horst, 2005). Monti et al. in Italy estimated that, for a 10 to 20 MW power plant burning 20% biomass, the required annual feedstock could come from medium-size farms within an area of 3000 ha (2009). In contrast, the Midwestern USA possesses low population density, an expansive and fertile land base, and a trend toward large-scale biorefineries.

In both the USA and EU, conversion pathways, i.e., how biomass will be made into more immediately useful energy forms, will also depend to some degree on the type of feedstock produced in the region. We can envision, however, that in areas to which multiple species might be adapted, the biorefinery (and its proprietary processes) will determine which crops are most widely planted. Where feedstock from a single crop may not be available at all times or may not provide sufficient tonnage, the introduction of multiple 2G crops into diverse agricultural matrixes could be desirable. Agronomic intensification strategies that diversify feedstock supply may come from the integration of

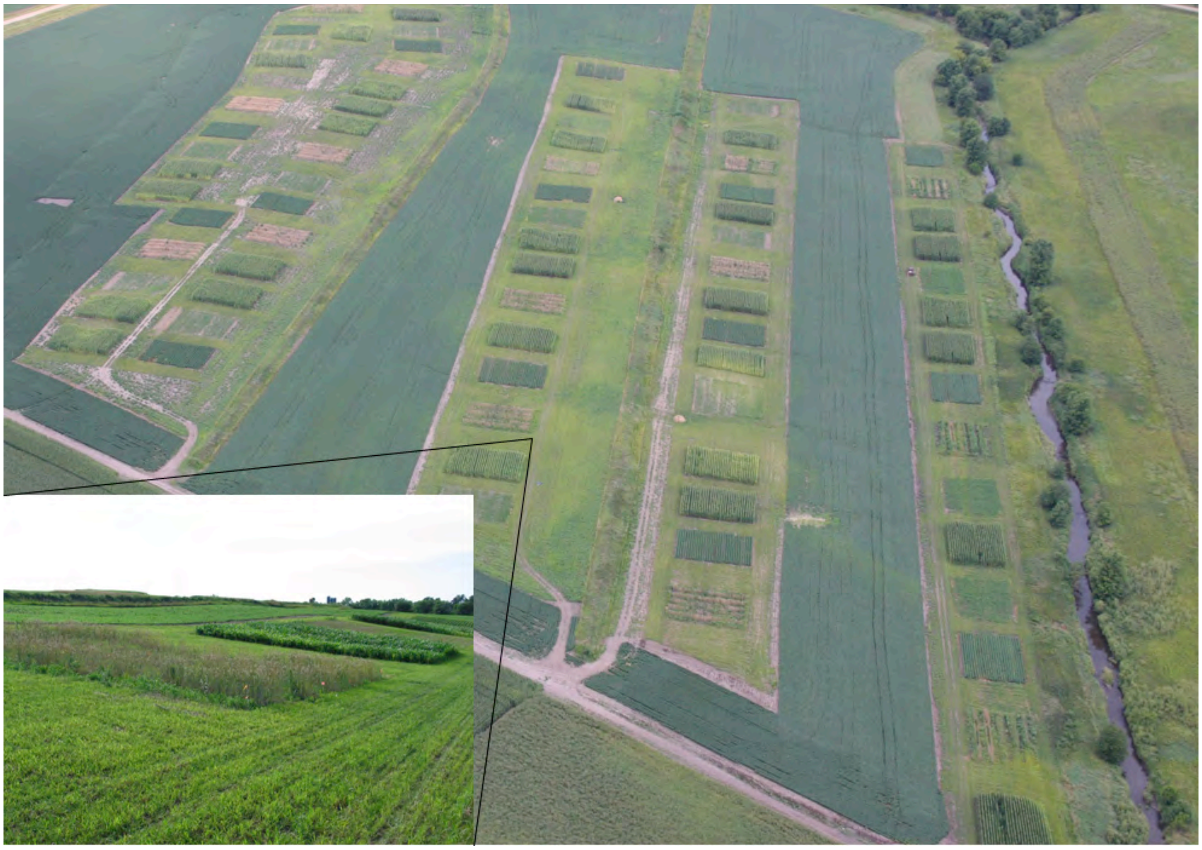

Figure 7. Aerial photograph of the Landscape Biomass experimental site near Boone, Iowa, USA taken in August, 2009. The Landscape Biomass Project uses evaluates conventional, temporal and spatial intensification strategies to understand how 2G energy crops can be integrated with annual row crops across a topographic gradient (slope). Bottom left inset shows ground view of backslope plots in replicate 1. Individual plot areas are ~ 0.05 ha with 6 m buffers between treatments. Photo credit: Tom Schultz (aerial) and Todd Ontl (inset).

a wide range of crop species and crop management intensities. The development of diversified management options will be crucial not only for the success of EU and US conversion facilities, but also for increasing global capacity to supply bioenergy while complying with political and energy security goals. Current understanding of trade-offs associated with diverse management options, such as those presented here, is, however, deficient. Serious effort should be directed to critical, comparative analysis of management strategies as an essential prerequisite to effective development of agricultural systems that can meet societal goals.

Infrastructure development still presents a major challenge for efficient 2G biofuel crop production and also needs to be considered in comparative analysis of land management scenarios. Techniques and equipment for efficient harvest, storage, delivery, handling, and processing of large volumes of feedstock are being developed but are strongly influenced by economies of scale. In general, it is expected that handling and storage techniques currently used for food and forage crops can be adapted to energy crops, yet real-world experience across the feedstock value chain is lacking (Paine et al., 1996). Logistically, feedstocks with high moisture content that are heavy or can decompose quickly, such as forage sorghum and short rotation coppice, could be especially problematic. Whatever the crop, the amount of biomass that can be harvested and transported out of the production area by the available machinery needs to be carefully managed. Oversized machinery and/or inappropriate operation (especially in winter harvests with wet conditions and/or soft soils) may pose serious threats to soil conservation and profitability of the system. Machinery optimization can have direct economic benefits as well. For example, harvesting efficiency was doubled from 41 to 84 Mg ha-1 of green (not dry) Populus spp. biomass in northern Europe when the harvester was used on level and solid terrain (Spinelli et al., 2008). Careful and detailed planning of harvest equipment, traffic routes, trucks, etc. is necessary for successful and sustainable management of agricultural systems.

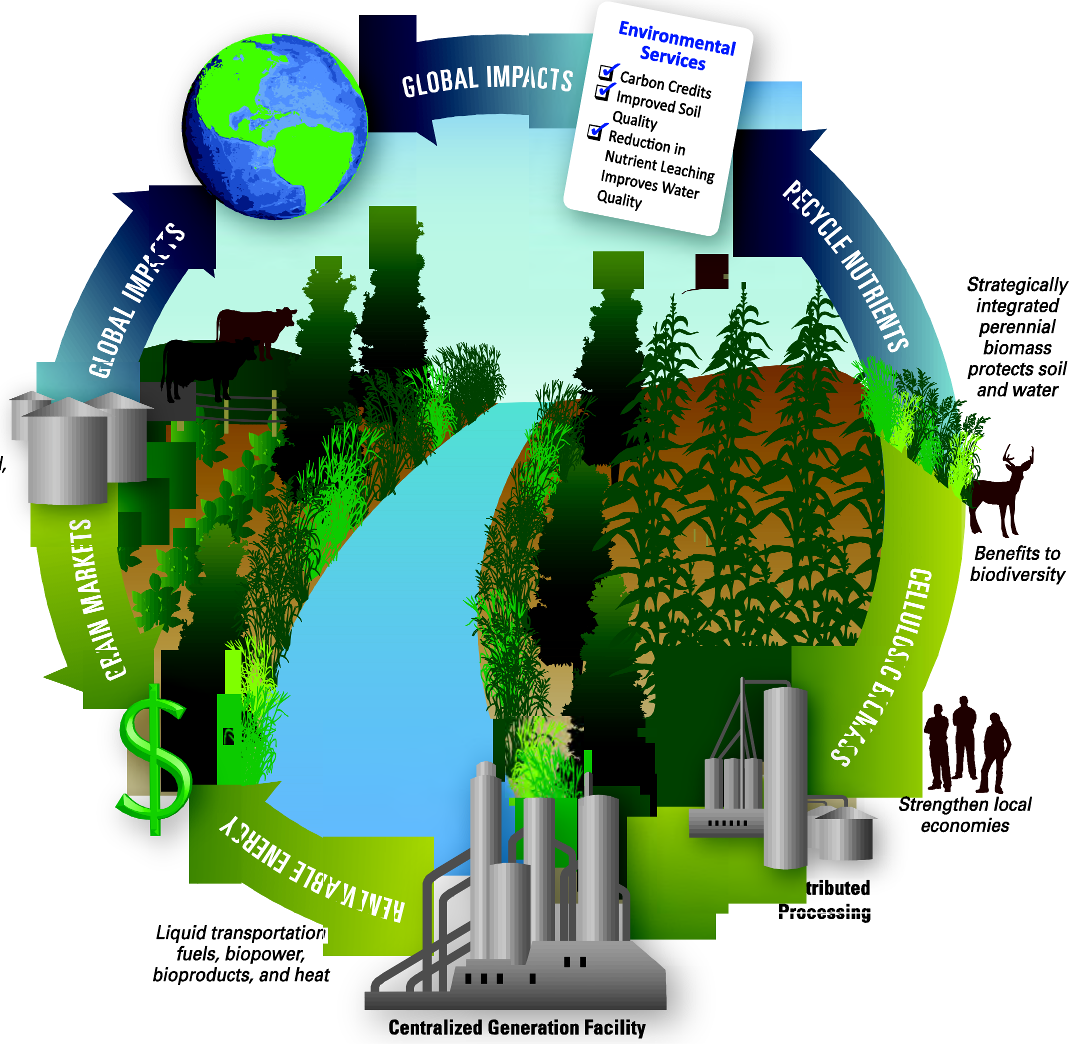

Figure 8. Stylized depiction of an integrated food and 2G fuel crop cropping system using an agroecological intensification approach. Conventional, temporal and spatial intensification strategies are combined to achieve high economic, ecological and social performance.

Conclusions

The multidimensional character of bioenergy and food production systems requires integrated research and management strategies. Improved understanding of food-energy-agriculture links can lead to more efficient management practices and the optimization of energy crop production under different scenarios. In the developed world, using sustainable intensification strategies that best match available resources and management tools to system outputs, e.g., food, feed, fiber, fuel, and ecosystem services, can enable the development of more economically robust and environmentally sustainable food and energy systems. Research and demonstration projects currently assessing agricultural intensification strategy implementation in the USA and EU will provide much-needed primary data for synthetic and critical analysis of expected tradeoffs with changes in management.

While efforts at conventional intensification will continue, more attention and investment in temporal and spatial intensification strategies could help overcome limitations associated with the current dependence on a relatively small number of industrial crops to meet all societal demands for agriculture. We posit that holistic agricultural intensification, or the strategic integration of food and 2G crops, has the ability to integrate bioenergy production with food/feed production in ways that simultaneously meet moral objectives and environmental goals (Somerville et al., 2010), thereby expanding the basket of goods 2G agroecosystems provide. We look forward to the proliferation of suitable primary data, such as those described here, that enables objective assessment of this hypothesis, and hopefully, a sustainable path forward for our planet.

Acknowledgements

This work was supported in part by CenUSA Bioenergy, a Coordinated Agriculture Project, through Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30411 from the USDA National Institute of Food and Agriculture and the National Science Foundation under Grant Number EPS-1101284. The STRIPS and Landscape Biomass Project examples presented here were funded by grants from the Iowa State University through the Iowa Agriculture and Home Economics Experiment Station (Projects IOW03803 and IOW05249), Leopold Center for Sustainable Agriculture, US Forest Service, and USDA National Institute for Food and Agriculture. DuPont Pioneer and DuPont Industrial Biosciences provided information about the Nevada (Iowa) Cellulosic Ethanol Facility. Meghann Jarchow, Anna MacDonald, Todd Ontl, and Tom Schultz provided images for use in figures. Special thanks to Danielle Wilson for technical support and comments on early manuscript versions.

References

Anderson-Teixeira KJ, Duval BD, Long SP, Delucia EH (2012) Biofuels on the landscape: Is “land sharing” preferable to “land sparing”? Ecological Applications, 22, 2035-2048.

Atwell RC, Schulte LA, Westphal LM (2010) How to build multifunctional agricultural landscapes in the US Corn Belt: Add perennials and partnerships. Land Use Policy, 27, 1082-1090.

Atwell RC, Schulte LA, Westphal LM (2011) Tweak, adapt, or transform: policy scenarios in response to emerging bioenergy markets in the US Corn Belt. Ecology and Society, 16, 10-25.

Berti MT, Samarappuli D, Nudell R, Johnson BL (2012) Croppng systems for biomass feedstock production in the North Central Region, USA. In: 20th European Biomass Conference and Exhibition. pp Page, Milan, Italy.

Bonin CL, Lal R (in press) Aboveground productivity and soil carbon storage of biofuel crops in Ohio. GCB Bioenergy, DOI: 10.1111/gcbb.12041.

Bramley RGV (2009) Lessons from nearly 20 years of precision agriculture research, development, and adoption as a guide to its appropriate application. Crop & Pasture Science, 60, 197-217.

Brussaard L, Caron P, Campbell B et al. (2010) Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability, 2, 34-42.

Bullock DS, Ruffo ML, Bullock DG, Bollero GA (2009) The value of variable rate technology: an information-theoretic approach. American Journal of Agricultural Economics, 91, 209-223.

Council NR (2009) A New Biology for the 21st Century, Washington D.C., The National Academies Press.

Cox Ohde R (2012) The use of reconstructed prairies in Iowa’s agricultural landscape to increase ecosystem services and move towards multifunctionality. Unpublished M.S. Thesis. Iowa State University, Ames, IA.

Dupont (2012) DuPont Nevada Site Cellulosic Ethanol Facility. pp Page.

Edan Y, Han S, Kondo N (2009) Automation in agriculture. Springer Handbook of Automation, 1095-1128.

Foley JA, Defries R, Asner GP et al. (2005) Global consequences of land use. Science, 309, 570-574.

Foley JA, Ramankutty N, Brauman KA et al. (2011) Solutions for a cultivated planet. nature, 478, 337-342.

Fouli Y, Duiker SW, Fritton DD, Hall MH, Watson JE, Johnson DH (2012) Double cropping effects on forage yield and the field water balance. Agricultural Water Management, 115, 104-117.

Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL, Robertson GP (2013) Sustainable bioenergy production from marginal lands in the US Midwest. nature, 493, 514-517.

Gesch RW, Archer DW (2013) Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. Industrial Crops and Products, 44, 718-725.

Godfray HCJ, Beddington JR, Crute IR et al. (2010) Food Security: The Challenge of Feeding 9 Billion People. Science, 327, 812-818.

Goff BM, Moore KJ, Fales SL, Heaton EA (2010) Double-cropping sorghum for biomass. Agron. J., 102, 1586-1592.

Gomiero T, Pimentel D, Paoletti MG (2011) Is There a Need for a More Sustainable Agriculture? Critical Reviews in Plant Sciences, 30, 6-23.

Gunther T (2011) Establishment of switchgrass in corn across a landscape gradient: establishment, yield, and quality of biomass feedstock. Unpublished MS Iowa State University, Ames, IA.

Gustavsson J, Cederberg C, Sonesson U, Otterdijk RV, Meybeck A (2011) Global food losses and food waste: extent, causes and prevention, Rome, Italy, Food and Agriculture Organization of the United Nations (FAO).

Heggenstaller AH, Anex RP, Liebman M, Sundberg DN, Gibson LR (2008) Productivity and nutrient dynamics in bioenergy double-cropping systems. Agronomy Journal, 100, 1740-1748.

Helmers MJ, Zhou X, Asbiornsen H, Kolka R, Tomer MD, Cruse RM (2012) Sediment removal by perennial filter strips in row-cropped ephemeral watersheds. Journal of Environmental Quality, 41, 1531-1539.

Hernandez-Santana V, Zhou X, Helmers MJ, Asbjornsen H, Kolka R, Tomer M (2013) Native prairie filter strips reduce runoff from hillslopes under annual row-crop systems in Iowa, USA. Journal of Hydrology, 477, 94-103.

Hirsh SM, Mabry CM, Schulte LA, Liebman M (2013) Diversifying agricultural catchments by incorporating prairie buffer strips. Ecological Restoration, 31, 201-211.

International Energy Agency (2013) Tracking Clean Energy Progress 2013. pp Page.

Johnson BL, Berti MT, Onemli F, Petersen PJ (2009) Double cropping sunflower after field pennycress in North Dakota. In: 21st Annual AAIC Meeting-The Next Generation of Industrial Crops, Processes, and Products. (eds Cermak SC, Berti MT) pp Page, Hotel Termas de Chillan, Chillan, Chile.

Knoke T, Roman-Cuesta RM, Weber M, Haber W (2012) How can climate policy benefit from comprehensive land-use approaches? Frontiers in Ecology and the Environment, 10, 438-445.

Lal R, Delgado JA, Groffman PM, Millar N, Dell C, Rotz A (2011) Management to mitigate and adapt to climate change. Journal of Soil and Water Conservation, 66, 276-285.

Macdonald AL (2012) Blurring the lines between production and conservation lands: bird use of prairie strips in row-cropped landcapes. Unpublished M.S. Thesis Iowa State University, Ames IA.

Macdonald JM (2011) Why are farms getting larger? The case of the U.S. In: Annual Meeting of the German Association of Agricultural Economists. pp Page, Halle, Germany.

Monti A, Fazio S, Venturi G (2009) The discrepancy between plot and field yields: Harvest and storage losses of switchgrass. Biomass and Bioenergy, 33, 841-847.

Munkholm LJ, Heck RJ, Deen B (2013) Long-term rotation and tillage effects on soil structure and crop yield. Soil and Tillage Research, 127, 85-91.

Nickerson C, Morehart M, Kuethe T, Beckman J, Ifft J, Williams R (2012) Trends in U.S. Farmland Values and Ownership. In: Economic Information Bulletin No. 92. USDA, Economic Research Service.

Odum EP (1969) The strategy of ecosystem development. Science, 164, 262-270.

Ontl T, Hofmockel KS, Cambardell CA, Schulte LA (2013) Topographic and soil influces on root productivity of three bioenergy cropping systems. New Phytologist, 199, 727–737.

Paine LK, Peterson TL, Undersander DJ et al. (1996) Some ecological and socio-economic considerations for biomass energy crop production. Biomass & Bioenergy, 10, 231-242.

Phalan B, Onial M, Balmford A, Green RE (2011) Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. Science, 333, 1289-1291.

Poet (2012) Ongoing research supports biomass harvesting for Project LIBERTY. pp Page.

Rupp SP, Bies L, Glaser A et al. (2012) Effects of bioenergy production on wildlife and wildlife habitat. In: Wildlife Society Technical Review 12-03. Bethesda, Maryland, USA, The Wildlife Society.

Schill SR (2007) 300 Bushel Corn is Coming. Ethanol Producer Magazine.

Schimmelpfennig D, Ebel R (2011) On the doorstep of the information age: recent adoption of precision agriculture. U.S. Department of Agriculture, Economic Research Service.

Schulte LA, Liebman M, Asbjornsen H, Crow TR (2006) Agroecosystem restoration through strategic integration of perennials. Journal of Soil and Water Conservation, 61, 164A-169A.

Somerville C, Youngs H, Taylor C, Davis SC, Long SP (2010) Feedstocks for Lignocellulosic Biofuels. Science, 329, 790-792.

Spinelli R, Nati C, Magagnotti N (2008) Harvesting short-rotation poplar plantation for biomass production. Croation Journal of Forest Engineering, 29, 129-139.

Thomson LJ, Hoffmann AA (2011) Pest management challenges for biofuel crop production. Current Opinion in Environmental Sustainability, 3, 95-99.

Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260-20264.

Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels from low-input high-diversity grassland biomass. Science, 314, 1598-1600.

Tilman D, Socolow R, Foley JA et al. (2009) Beneficial biofuels-The food, energy, and environment trilemma. Science, 325, 270-271.

Tscharntke T, Clough Y, Wanger TC et al. (2012) Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv., 151, 53-59.

Tyndall J, Helmers M, Liebman M, Schulte LA (2013) Field-level financial assessment of prairie strips for enhancement of environmental quality. Environ. Management.

Usda (2013a) Conservation Reserve Program Statistics. USDA, Farm Service Agency. http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st

Usda (2013b) US Bioenergy Statistics. USDA, Economic Research Service. http://www.ers.usda.gov/data-products/us-bioenergy-statistics.aspx

Van Den Horst D (2005) UK biomass energy since 1990: the mismatch between project types and policy objectives. Energy Policy, 33, 705-716.

Walthall CL, Hatfield J, Backlund P et al. (2012) Climate Change and Agriculture in the United States: Effects and Adaptation. In: USDA Technical Bulletin 1935. Washington, DC.

Xu BC, Li FM, Shan L (2008) Switchgrass and milkvetch intercropping under 2 : 1 row-replacement in semiarid region, northwest China: Aboveground biomass and water use efficiency. European Journal of Agronomy, 28, 485-492.

Xu BC, Li FM, Shan L (2010) Seasonal root biomass and distribution of switchgrass and milk vetch intercropping under 2:1 row replacement in a Semiarid Region in Northwest China. Communications in Soil Science and Plant Analysis, 41, 1959-1973.

Zhou X, Helmers MJ, Asbjornsen H, Kolka R, Tomer MD (2010) Perennial filter strips reduce nitrate levels in soil and shallow groundwater after grassland-to-cropland conversion. Journal of Environmental Quality, 39, 2006-2015.