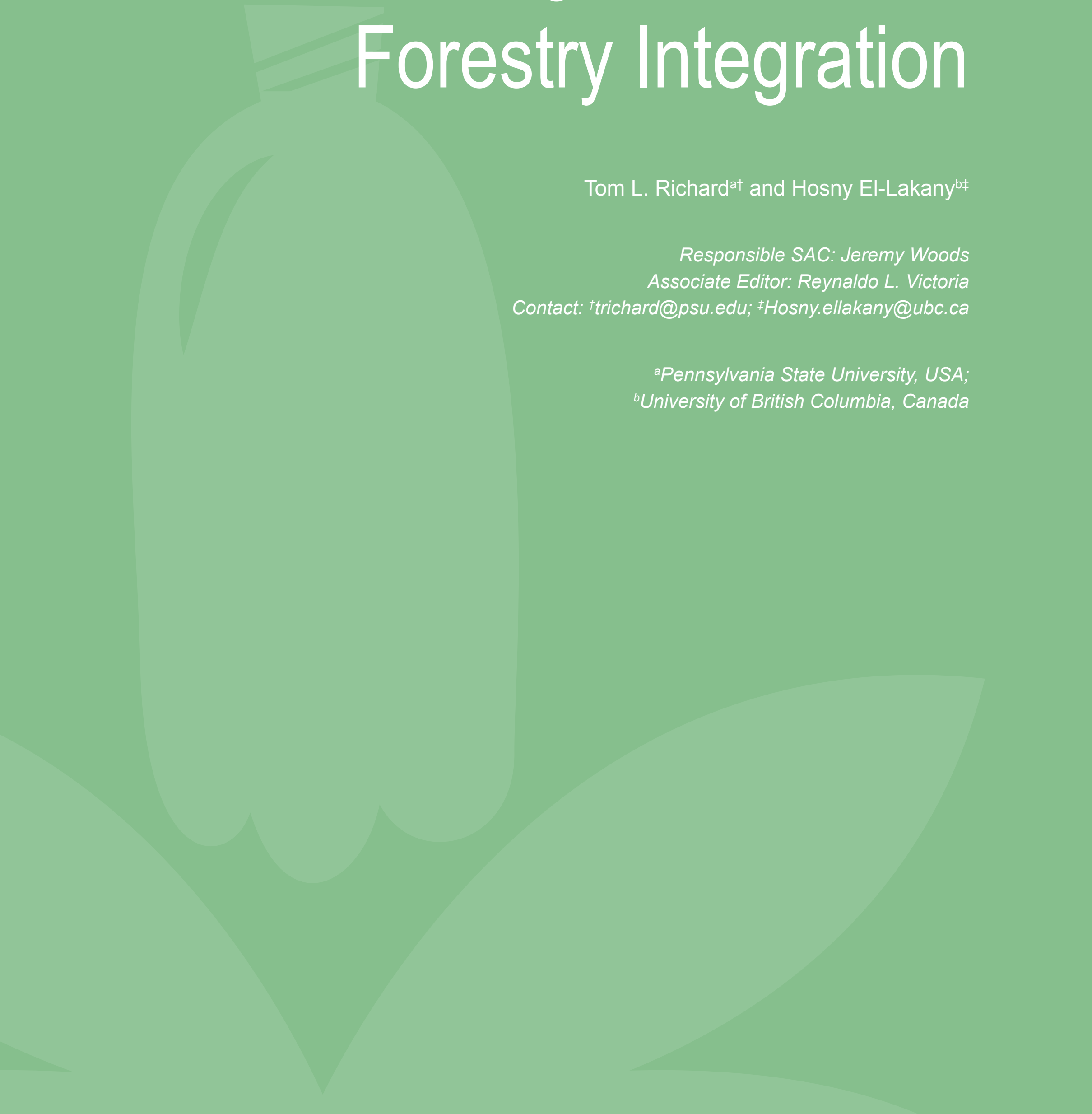

chapter 13

Agriculture and Forestry Integration

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Highlights

- Integrated agricultural and forest systems have provisioned societies for millennia.
- Integration can occur in space (agroforestry) or time (perennial rotations).
- Recycling mass and energy among components can increase system efficiency.
- Diverse, integrated systems require investments in human and financial capital.
- Sustainable implementation requires effective governance at local to global scales.

Summary

Integration of agriculture and forestry can increase production, enhance ecosystem services, and reduce development pressure on unmanaged ecosystems. Several systems have been developed that demonstrate complementary plantings of woody species, perennial and annual grasses and food crops can intensify production for greater yields, while more efficiently utilizing water and nutrients. These systems can incorporate spatial diversity through strategic placement of perennial bioenergy crops across the landscape, as well as temporal diversity through crop rotations that include annual and perennial energy crops coupled with food or fiber production. Expanding markets for bioenergy products and co-products can facilitate rural development and form a platform for both socio-economic and ecological benefits.

13.1 Introduction

Agricultural and forest landscapes have long provided humans with food, fiber and energy as well as a range of other ecosystem services. In developing regions, about one third of traditional biomass energy is supplied from forests, with two thirds from other sources including crop residues, livestock manures, and especially "Trees Outside Forests", i.e. trees interspersed in agricultural cropland and grasslands (FAO 1997). In sheer volume these systems consume more biomass for energy than for pulp and paper or lumber. The FAO (2010a) estimates that more than half of global wood removal is consumed as woodfuels, much of which is for subsistence use or informal trade. As a percentage of total energy consumption, developing countries use more renewable energy than developed countries, mainly due to the vast amounts bioenergy derived from forests and agriculture. While these traditional bioenergy systems sometimes result in ecological disruption and deforestation, many are illustrative of the multi-functional landscapes that are today viewed as harbingers of sustainability (Wiggering et al. 2003; Jordan and Warner 2010).

Several studies have shown there is considerable potential for increasing bioenergy production even further, to meet a substantial fraction of future energy needs (Smeets and Faaij 2007; Somerville et al. 2010). Bioenergy development potentially offers poor countries many advantages, ranging from energy security to poverty reduction, infrastructure development and economic growth (FAO 2010a, Cushion et al. 2010). Yet there are also concerns about food security, especially in regions with widespread poverty, unstable governments, and fragile agricultural systems, and these challenges are likely to be exacerbated with accelerating climate change (Brown and Funk 2008). Effects on the environment are also variable, depending on feedstock type, location, and both prior and future management. While perennial biofuel feedstocks can improve soil quality and biodiversity, reduce greenhouse gas emissions and enhance water quality, some industrial models of modern biofuel production can negatively impact ecosystem services through intensive fertilizer and chemical use, grassland conversion and deforestation (Raghu et al. 2011; Gao et al. 2011; Pacheco et al. 2012).

This chapter examines the forestry-agriculture-biofuel nexus from both production and consumption perspectives. It looks at the interdependencies and complementarity of resource management policies that govern these sectors, and ways to enhance the synergies between the food, bioenergy and biomaterials industries. Special attention is given to strategies that can make agriculture and forestry more sustainable using biofuel production systems. Of particular interest are co-production of timber, food and bioenergy in integrated landscapes (land sharing), ecological intensification to increase production and minimize the need for indirect land use change (land sparing), and efficient value chains that optimize use of by-products, co-products and recycling (industrial ecology). These complementary management approaches include strategies for integration on both spatial and temporal scales, with bioenergy production placed on the most appropriate places on the landscape, and/or integrated in crop rotations with food and fiber production. The focus is on the principles and practices needed to design and implement sustainable bioenergy systems.

13.2 Forestry/Agriculture Interface

Since the dawn of agriculture humans have been converting forestland to cropland, to the extent that today many forest ecosystems are at risk. In this context it is not surprising that large-scale expansion of bioenergy, with increased demand for agricultural and forest biomass, is seen as a major threat. FAO estimated the world's total forest area[1] in 2010 at just over 4 billion hectares, which corresponds to an average of 0.6 ha per capita (FAO 2012). Between 2000 and 2010, around 13 million hectares of forestland were converted to other uses or lost through natural causes each year, down from roughly 16 million hectares per year in the 1990s. While the overall rate is slowing, the distribution is highly variable. Between 2000 and 2010 South America suffered the largest average net loss of about 4.0 million ha annually, followed by Africa with 3.4 million ha, then Oceania with 0.7 million ha. In Asia there is still a high rate of loss in many countries in South and Southeast Asia, but the region as a whole gained some 2.2 million ha annually between 2000 and 2010 mainly due to large scale tree planting in China, a reversal from the net forest cover loss of nearly 0.6 million ha annually in the 1990's (FAO 2010d). Reforestation, afforestation and natural expansion of forests are reducing the net loss of forest area significantly at the global level. By 2010, planted forests and reforestation made up an estimated 7 percent of the total forest area, totaling 264 million hectares (FAO 2012).

Over millennia, forests played a significant role in food security and have been regarded as safety nets for subsistence farmers. Nevertheless, many researchers and policy analysts have observed that conversion to agriculture, both for commercial and subsistence ends, is the primary driver of forestland clearing. This permanent conversion to agricultural land use has dramatically different effects than traditional shifting cultivation. According to Mertz (2009), and others, shifting cultivation by subsistence farmers 1) enables greater carbon sequestration than other forms of land use, 2) enhances biodiversity, and 3) is crucial for *in-situ* conservation of crop genetic resources. Conventional agriculture based on annual grain crops drives all three of these sustainability metrics in the opposite direction, yet is encouraged in many countries by land tenure policies, public investments in transportation hubs and centralized market infrastructure, and eligibility rules for agricultural subsidies.

In this context, the growing demand for food, fuel and fiber associated with global population growth, rising incomes and changing diets continues to drive deforestation (Kastner et al. 2012). Gibbs et al. (2010) estimated that during the period from 1980 to 2000, over 80% of new cropland in the tropics was converted from forests, 55% from primary forests and another 28% from secondary forests. While forest protection policies and especially increasing afforestation and reforestation have slowed the rate of decline, the conversion of natural ecosystems to cropland and other uses still causes major losses of biodiversity, water quality and quantity, terrestrial carbon storage, and other critical ecosystem services.

The forestry-agriculture nexus is clearly demonstrated by contrasting models of food, animal feed, fiber and fuel production and consumption. In many parts of the world traditional systems provide all of these products (and others) simultaneously. However,

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[1] Forests are defined as "Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use". (FAO 2010c).

the dramatic surge in industrial monoculture approaches has introduced imbalances in land use systems, especially in tropical regions. This environmental change is often coupled with rapid social change and controversy driven by unstable land tenure and inequitable government policies and practices.

Growing demand for biofuel feedstocks tends to add to existing pressures on tropical forests, although these pressures vary across regions (Pacheco et al 2012). Expansion of first generation biofuel crops has been reported to have negative impacts on forests and food security due to direct and indirect land use changes (Fisher et al. 2009; Havlik et al. 2011). The indirect effects can be thought of as any losses of forest or savannah required to replace the pasture or cropland directly converted to bioenergy production. These indirect impacts are difficult to measure, and are estimated by models and statistical approaches that use varying assumptions about system boundaries, soil carbon and greenhouse gas implications, demand elasticity and economic equilibrium for food and other commodities (Fargione et al. 2008; Searchinger et al. 2008; Gao et al. 2011). These assumptions can result in substantially different estimates of the impact of biofuel development on deforestation, as illustrated by studies attempting to quantify these effects for the Brazilian Amazon (Lapola et al. 2010; Arima et al. 2011). Despite this uncertainty, there is broad agreement that large-scale conversion of food cropland or natural forests to biofuel production should be treated with caution.

There are a variety of negative social impacts of uncontrolled agricultural expansion into forests associated with biofuel production. Medium- and large-scale plantations for bioenergy and other uses stimulate concentration of land ownership, which may displace local people and threaten their livelihoods (Pacheco 2012). There is a clear need for transparent and equitable governance policies associated with investments in bioenergy feedstock production at the agriculture – forest interface, coupled with effective law enforcement and implementation of social and environmental safeguards and regulations. Compliance must be reinforced by consistent forest and agricultural policies at the local, national and international levels, with buy-in from the full range of stakeholders, especially the private sector.

13.3 New Paradigms in Ecological Land Management

Although the recent history of biofuel development has reinforced perceptions of conflict between food, energy, and other ecosystem services, synergistic interactions are also possible. From the perspective of food security and sustainable landscape management, FAO (2008) stated that “biofuel expansion may represent not only additional stress but also opportunities that affect all four dimensions of food security – availability, access, stability and utilization”. Just as diversity in natural ecosystems can increase resilience, a broader portfolio of products and markets can improve ecological performance but also encourage infrastructure development, improve income stability, and strengthen rural communities.

The evolving paradigm in sustainable natural resources management, often referred to as ecological land management, calls for recognizing the economic, environmental and social interdependencies of these resources, then exploring integrated and complimentary management systems. Cushion et al. (2010) recommended the evaluation of trade-offs related to poverty, equity and the environment when developing a bioenergy system. Included among these trade-offs are the opportunity costs of forgone options, which in land use include prospects of alternative trajectories of development, but also of maintaining natural ecosystems for wildlife, biodiversity and other ecosystem services (Fischer et al. 2008). Several emerging approaches to ecological land management illustrate ways that bioenergy crops can increase complementarities and synergies.

13.3.1 High Productivity Polyculture Systems

Natural forests and grasslands in both tropical and temperate regions represent productive ecosystems with diverse plant and animal communities that efficiently utilize water, nutrients, and light. However, these natural ecosystems are rarely compatible with industrial planting and harvesting technologies, and are often replaced with monocultures of woody or herbaceous species that with inputs of fertilizer and pesticides may produce higher yields. This sort of land use change constitutes both an immediate threat to biodiversity and a long-term one to the productivity of the landscape (FAO 2008).

Recent research has demonstrated that managed polycultures of bioenergy crops can reproduce much of the diversity, resilience, and nutrient use efficiency of natural ecosystems while still achieving reasonable yields. Such systems include artificial or successional prairies that can include grasses, forbs and legumes playing different ecological roles (Tilman et al. 2006; Gelfand et al. 2013), polycultures of tree plantations (Erskine et al. 2006), and interplanting of perennials with high yielding annuals or trees (Manatt 2013) (see Figures 13.1 and 13.2). Diversity of species and even varieties can more efficiently recycle nutrients and capture water and light, provide refuge for beneficial insects, and limit the reproduction and damage from pests and disease (Gurr et al. 2003).

The diversity of polycultures is also likely to improve the resilience of agricultural systems, minimizing yield losses from weather extremes including flooding and drought. These ecological and agronomic benefits can translate into human benefits as well, with both polyculture systems and perennial crops considered important strategies within the framework of ‘climate-smart agriculture’.

The goals of climate-smart agriculture, “to simultaneously improve food security and rural livelihoods, facilitate climate change adaptation and provide GHG mitigation

Figure 13.1. Integration of food and energy crops can be spatial (left) or temporal (right), in either case increasing ecosystem services and biodiversity relative to annual monocultures (center). Photos courtesy of ICRAF (left), Lynn Betts (center) and anonymous (right) of the USDA Natural Resources Conservation Service.

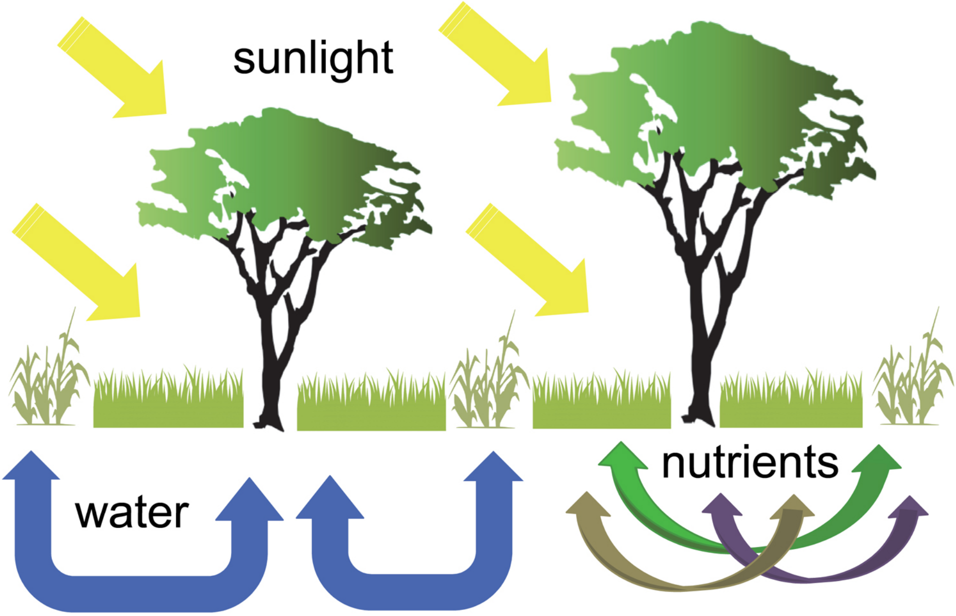

Figure 13.2. The ecological structure and biodiversity of polyculture plantings allows more efficient utilization of sunlight, nutrients and water, as well as pest and disease management.

benefits" (FAO 2010b), provide a platform for new linkages between climate science and more resilient and sustainable agricultural systems. However, "integrated landscape management" provides an alternative and complementary organizing framework for policy development and implementing new strategies for agricultural development and conservation communities (Scherr et al. 2012). Biomass production systems, because of the diverse options for perennials and polycultures, have considerable potential to be major components of both integrated landscape management and climate-smart agriculture.

13.3.2 High Productivity Monoculture Systems

Although polyculture systems are likely to maximize ecosystem services for the reasons previously described, in many cases highly productive monocultures are able to maximize biomass yield and economic returns. While monocultures are by definition less diverse than polycultures, integration of energy crops with food crops can significantly increase the diversity of agricultural landscapes in both space and time (see Figure 13.1). Many of the highest yielding energy crops are perennials, including sugarcane, miscanthus, switchgrass and short rotation woody crops like poplar and shrub willow. Perennials are often planted for their ecosystem benefits, which include reducing erosion, increasing soil organic matter and nutrient retention, thus enhancing soil health and water quality (Smith et al. 2013, Mitchell et al. 2010). On steep slopes, as streamside buffers, and on droughty or poorly drained soils, perennial energy crops can provide energy yield from parts of the landscape where soils are fragile and annual food crops are at greater risk of crop failure. Additional detail about the production practices and ecosystem benefits of these perennial energy crops are provided elsewhere in this book (see especially Chapters 10, 16, and 18, this volume).

Strategic placement of energy crops can occur in time as well as in space. With the increase of mechanization reducing demand for winter feed grains on many farms, winter fallow is common in many temperate cropping systems. In the US these winter crops could increase bioenergy feedstock potential by at least 10% with no new land requirements, while also enhancing soil and water quality (Feyereisen et al. 2013, Manatt et al. 2013). Although winter double crops may require additional inputs including fertilizer, harvested nutrients from these crops can be recycled from biorefinery byproducts as fertilizer (Heggenstaller et al. 2008). Traditional breeding programs for summer annuals have often assumed that longer growing seasons had no opportunity cost, even though the increases in yield from extended seasons can be relatively small. Yet for winter crops, even two weeks of additional growing season can increase yields by 15 to 30% (Feyereisen et al. 2013). Integrated, multi-species breeding programs are needed that exploit the potential synergies of nutrient use and water uptake efficiency for coupled summer and winter annuals to maximize the productivity of the crop rotation system.

Box 13.1. Integrating energy crops requires sustainable management strategies

"Bioenergy crops are often classified (and subsequently regulated) according to species that have been evaluated as environmentally beneficial or detrimental, but in practice, management decisions rather than species per se can determine the overall environmental impact of a bioenergy production system. Prior land use, harvesting techniques, harvest timing, and fertilization are among the key management considerations that can swing the greenhouse gas balance of bioenergy from positive to negative or the reverse…

The international debate about the benefits of biofuels is not likely to be resolved with a generalized view of bioenergy impact assessment because management approaches vary regionally. A diversified assessment approach is needed to account for many management practices that can swing the overall impact of bioenergy crop production from negative to positive or vice versa. The management swing potential is a key part of the sustainability puzzle, but is underrepresented in the policy debates that will decide the future role of bioenergy in mitigating climate change" (Davis et al. 2013)

13.3.3 The Green Economy

The Green Economy as related to bioenergy is a term that captures many aspects of sustainable development and innovation (Chapter 6, this volume). While "green" is often considered a catch-all term for a range of sustainability issues, from a forestry/agriculture perspective there are specific opportunities for national and global economies to shift to products that are based on photosynthesis, especially increasing use of feedstocks from sustainably managed farms, forests, and other cellulosic biomass resources.

In order to fully realize the potential of forestry and agriculture in the "Green Economy", two types of policy reforms are needed. First, there is a need for effective incentives for improved management and new investments in sustainable feedstock production. And second, because of the large inertia and sunk investment in traditional and often exploitative approaches, governments and markets must create disincentives to unsustainable practices. Positive incentive programs are already developed for certification of sustainable forest management with respect to lumber, paper, and other materials, and for sustainable agricultural systems with respect to food. The Roundtable on Sustainable Biofuels (2013) is one of several such programs that are now being developed for bioenergy systems. In most countries such market-based programs are voluntary and there are no formal disincentives to prevent unsustainable practices, although government subsidies are sometimes withheld.

Incorporating bioenergy into these emerging green economy programs offers tremendous potential to harness the power of the marketplace. However, the metrics for these programs vary quite widely. Bioenergy feedstock assessments focus primarily on greenhouse gas emissions, energy, and land use change (van Dam et al. 2010) while food and timber assessments focus more on chemical toxicity, soil fertility and ecosystem protection (Cashore 2002, Raynolds 2004). More comprehensive sustainability assessments can include a wider range of environmental as well as economic and social indicators, and there is some effort to develop standard, quantifiable sets to facilitate consistency and communication (Dale et al. 2013; Efroymson et al. 2013). Integration and optimization of these global and local environmental and socio-economic criteria will require considerable research and policy analysis to optimize and harmonize these programs equitably (Raynolds 2004; McBride et al. 2011; van Noordwijk et al. 2012).

There is a considerable potential for increasing the use of forest and agricultural residues as bioenergy feedstocks. Land productivity can be defined as the efficiency by which a particular crop and management system uses sunlight and other inputs to provision various human needs, and systems that utilize multiple co-products, byproducts and wastes can increase that efficiency and productivity. Co-products and byproducts can be differentiated by their quality and efficiency (see Figure 13.3), creating a hierarchical cascade of value. Processing facilities can be developed that use biomass for more than

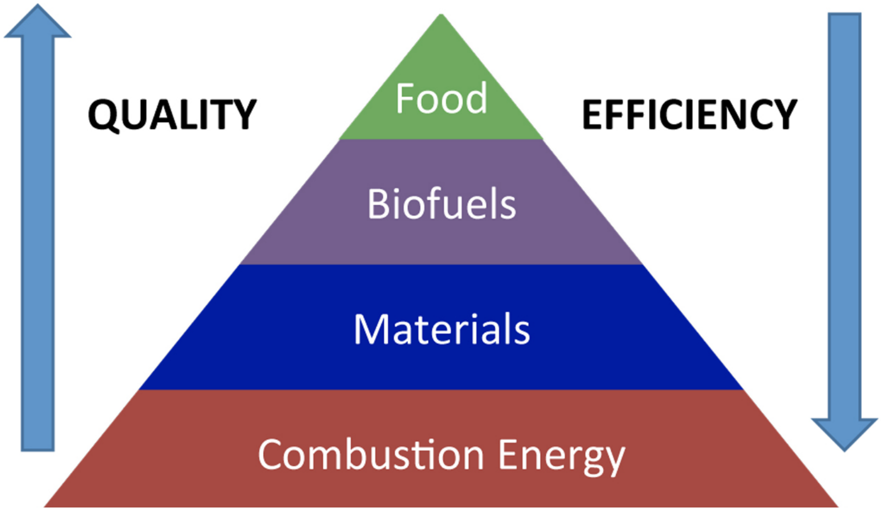

Figure 13.3. The quality (or value) of agricultural and forest products is often inversely proportional to the efficiency (or yield) of the crop. Integrating bioenergy creates opportunities to increase overall system value and efficiency.

one purpose, with biomass as a feedstock providing industrial power for fuel, chemicals and materials (Wang et al. 2007). Some valuable co-products can be separated at the front end of processing, and used for chemicals and materials, while residues can be separated later in the process. Cushion et al. (2010) concluded that co-firing already renders some timber processing and bioenergy operations energy self-sufficient, while ethanol refineries powered by sugarcane bagasse in Brazil even export electricity to the grid (Jofsetz and Silva 2012). The huge quantities of waste products from saw- and paper-milling operations have significant potential for power generation that is not fully utilized, especially in developing countries. Most of the initial cellulosic biorefineries are sourcing crop residues and wood waste as both fuel feedstocks and a source of industrial power (USEPA 2013).

In fully integrated systems, it is important for wastes and byproducts to move in both directions – agricultural and forest residues as industrial feedstocks, but also biorefinery residues and byproducts as agricultural inputs (see Figure 13.4). First generation biorefineries have done this effectively, producing high value animal feeds from both ethanol (distillers dry grains and solubles) and biodiesel (soymeal and canola meal) operations. These recycling strategies improve not only environmental performance, but economic performance as well, with animal feed coproducts providing from 16% to over 50% of first generation biorefinery income (Taheripour et al. 2010). Second generation biorefineries can expand these byproduct recycling strategies to include new kinds of animal feed (Dale et al. 2010; Bals and Dale 2012) and fertilizers as well (Anex et al. 2007).

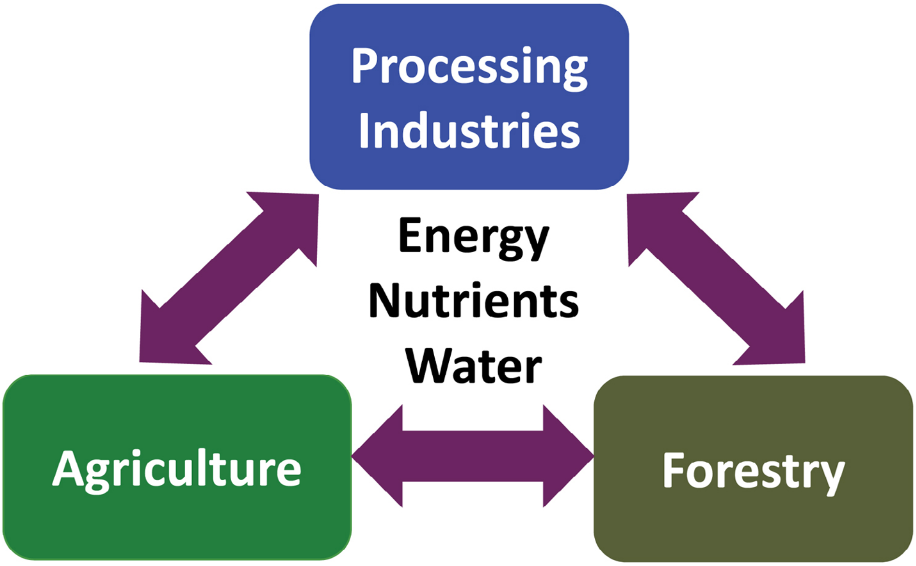

Figure 13.4. Integration of agriculture and forest systems with processing industries increases the opportunities for positive feedback loops that reuse and recycle mass and energy flows and improve system performance.

13.4 Integrated Landscape and Bioenergy System Design

Previous sections of this chapter have outlined several opportunities for integration of bioenergy feedstock production with agricultural and forest landscapes as well as industrial food and energy systems. There is a clear need to not just integrate but also optimize these value chains at each step: on-farm, at distributed preprocessing locations, and at centralized biopower and biorefinery facilities. The benefits of these integrated systems should be evaluated for economic and environmental benefits as well as risks and resilience, and trade-offs should be made explicit for business and policy decisions.

While integrated system design and evaluation is a complex challenge, a powerful suite of planning and analysis tools are available to facilitate this process. These include spatially explicit databases and models (Natavi et al. 2013; Leonard and Duffy 2013) and life cycle assessment tools for both production and conversion (Camargo et al. 2013; Wang 2001). Together, these tools can create a knowledge system that can inform decision makers about their choices and the options available to address these decisions (Herrick et al., 2006; Reid et al. 2010). But a critical remaining challenge is to develop effective mechanisms by which such integrated decisions can be coordinated and implemented. There are serious disparities in scale between land tenure, parcel sizes and conversion technologies, which vary in different localities, as well as different incentives for owners and managers of land, supply chain, conversion and distribution businesses. Aggregating individual incentives for collective benefits will require a realignment of policy and economic incentives with social criteria to encourage integrated and equitable business models.

The discussions related to policy frameworks for climate change, forestry, agriculture and bio-energy have been splintered over several international and national forums in the last few years. One of the initiatives that has potential to integrate policies governing landscape management systems is REDD+[2]. Although it was originally conceived as a market approach to reduce deforestation and forest degradation and the greenhouse gas emissions associated with that land use change, it has come to be used for broader forest preservation purposes. The assumption behind REDD+ is that compensating countries for the returns from converting forest land, i.e. paying the opportunity costs of land conversion would deter them from deforestation. However, several researchers have challenged this assumption. For example, Gregersen et al. (2010) have shown that it might be difficult to estimate opportunity costs correctly in some regions where deforestation is high and market systems are not functioning well. Furthermore, opportunity cost may be an inadequate incentive to reduce deforestation in regions where illegal logging and

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[2] REDD+ is “Reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries”. http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

corruption are common, transparency and accountability are weak, land tenure rights are not clear, and/or technical and financial capacities are inadequate.

More recently, agriculture broke into the REDD+ international arena, perhaps driven by close connections among climate change, forestry and agriculture as well as the enormous amounts of donor funds promised or made available to various developing countries. While coupling climate mitigation programs with food production is fraught with potential obstacles (Kissenger 2011), REDD+ strategies could be used to create incentives to produce biofuels on degraded landscapes while protecting and enhancing food production on priority sites.

While REDD+ is driven by governmental policy, its implementation includes market-based systems to encourage integrated multi-criteria optimization, similar to established and emerging certification processes for sustainable forestry (Cashore 2002) and biofuel production (van Dam et al. 2010, Roundtable of Sustainable Biofuels 2013). These processes can encourage decision makers to take a more holistic view of the bioenergy systems and discover the synergies that often result from an integrated management perspective.

13.5 Integrated Natural Forests, Planted Forests, Agroforestry, and Restored and Artificial Prairie Systems as Sources of Biomass - Potentials and Challenges

With the depletion of natural forests in many countries, there is a growing interest in forest tree planting for multiple objectives including bioenergy uses such as fuelwood and biofuel feedstocks. While converting diverse natural forests to monoculture forest plantations has many negative attributes as described in section 13.2, there are other land use options to consider. Increasingly, nations are using public investment and public-private partnerships to reclaim degraded landscapes and marginal land with managed forests and perennial grasslands. These reclamation efforts may be motivated by environmental or energy security concerns, but are enabled by increasing agricultural productivity, more stable agricultural trade, and improving food security (Lele et al. 2012). Framing these reclamation efforts as multifunctional landscapes offers considerable opportunity to enhance agriculture – forest integration.

Planted forests have, and will continue to play an increasingly significant role in supplying raw forest products, including biofuels. Public and private investment in forest plantations is growing at a fast rate around the world, but mostly in the tropics and sub-tropics where growing conditions are favorable and management costs are reasonable. Some of the tree plantations are dedicated for bioenergy as a primary product, while the majority of plantations are managed to reduce the pressure on natural forests by producing a variety of wood and other forest products. More recently, some planted forests have been established for the sequestration and storage of carbon but the rate of establishment fluctuates depending on the carbon market (IPCC 2014).

The areas of degraded and deforested land worldwide are huge with the available estimates ranging from 1 to 2 billion hectares depending on the source of information (The Global Forest and Landscape Restoration Partnership 2013). Based on the economic, environmental and social parameters of project feasibility, large areas could be transformed into resilient, multifunctional assets that would contribute to local and national economies, sequester significant amounts of carbon and safeguard biodiversity. Analysis by Schoneveld (2010) has shown that there is sufficient marginal and degraded land available for cultivating bioenergy crops in developing countries.

The local socio-economic impacts of biofuel feedstock development are extremely variable (Pacheco et al. 2012). In some cases, feedstock plantations accrue benefits for job and income generation, and for boosting incomes of small-scale farmers engaged in production. In others, plantation development may threaten the livelihoods of native populations as well as reduce opportunities to restore landscapes, especially where insecure tenure rights tend to prevail.

As a complement to extensive forest plantations, partnerships between private sector corporations and small farmers have often proved to be beneficial. Such outgrower schemes have also been common for some time in agriculture, with business networks that aggregate small lots of grain or other commodities into larger lots that can attract market attention. Short rotation woody crops offer one option for intensive, high yield and somewhat scale-neutral production by individuals landholders (Volk et al. 2006). Innovative business models will be necessary to support and reward smallholder production in bioenergy supply chains, especially for the large biorefineries needed to achieve economies of scale in production of biofuels.

Small wood-lots, shelterbelts, farm windbreaks and other woody perennials constitute a valuable component within farming systems that have been both a traditional land-use and a livelihood option developed by subsistence farmers. Agroforestry systems are quite diverse and range from fruit and other treecrops in home gardens, subsistence livestock and pastoral systems, alley intercropping of trees with herbaceous row crops, and biomass plantations. While there are trade-offs associated with conversion of natural forests to agroforestry systems, under certain circumstances these systems may represent an appropriate solution to the dual and often conflicting challenges of socio-economic development and environmental protection (Steffan-Dewenter et al. 2007). In many other cases, introduction of agroforestry approaches to agricultural systems or degraded lands can enhance productivity and conserve natural ecosystems. Agroforestry systems already cover roughly half of the land associated with agriculture. Estimates indicate that out of the total global farm land area of over one billion ha, about 430 million ha have tree cover greater than 10%; of which 160 million ha have more than 50% tree cover (Dawson et al. 2012). This landscape already represents a huge resource of timber and non-timber products and services ranging from solid wood to food, fodder, rubber and other chemical products, fuel-wood, wind and water erosion control and carbon sequestration. When properly planned and sustainably managed in agroforestry systems, much of this resource could provide a significant bioenergy raw material.

An important consideration in all these systems is effective management of land use transitions. The challenge is to achieve successful establishment of a productive biomass system while minimizing the carbon footprint associated with land use change. This is particularly problematic for land that is in forests or established perennials, where trees and grasses have already accumulated carbon in their above ground biomass as well as in the soil. In such circumstances convention land clearing and establishment strategies for biofuel production can create a carbon debt that requires decades to repay (Fargione et al. 2008). Alternative establishment strategies, such as using mowing and harvesting to transition old-field succession into bioenergy systems without disturbing the soil, can result in highly productive artificial prairies and agroforestry systems. Such strategies can reduce the life-cycle greenhouse gas footprint significantly relative to conventional approaches to establishing perennial monocultures of grasses or trees (Gelfand et al. 2013).

Landscape restoration, including through tree planting and prairie reconstruction, is a nature-based solution – going beyond conventional approaches and cutting across sectors, and has gained considerable attention lately. Multifunctional mosaics of tree-lots and cropland developed as an approach to landscape restoration schemes support the livelihoods of smallholders in addition to other economic, environmental social goods and services. Bioenergy markets can thus provide additional incentives for positive social and ecological change for the restoration of degraded landscapes.

13.6 Conclusions and Policy Recommendations

Integrated food/forest/energy systems, i.e. growing energy crops and food or fiber crops in synergy, can be accomplished with either spatial approaches (strategic placement on the landscape) or temporal approaches (crop rotations and succession plantings). These strategies can produce substantial amounts of energy and reduce soil erosion, provide wind protection and contribute to climate mitigation, which in the long run will improve the yield and quality of food and fiber crops. Integration can also occur at a system level, with residue recovery, nutrient and energy recycling and waste reduction addressing sustainability challenges of our conventional food and energy systems.

Harmonizing forestry and agriculture policies is fundamental for the implementation of integrated approaches to sustainable production and supply of bioenergy. This chapter shows the interrelationships and interdependencies of policies governing the three sectors. Beyond that, it demonstrates that the development of bioenergy production schemes within forestry and agriculture systems presents the developers and policymakers with economic, social and environmental opportunities and challenges. Land-use changes associated with integrated food, fodder, fiber and/or fuel production systems are likely to be significant, and can enhance or detract from ecosystem services depending on design, implementation and management.

Regulations that ensure the sustainability of biofuel-specific agriculture and forestry practices have not yet been developed in many countries. The necessary legal and institutional frameworks are also lacking, particularly those related to land tenure and customary land rights.

As we look toward the future, it is clear that global policy frameworks should more explicitly address bioenergy production and provide appropriate incentives for sustainable integration with food and timber production. Such policies must have the flexibility to adapt to local social and biophysical circumstances, yet also drive management practices that achieve global greenhouse gas reduction goals. As this chapter has demonstrated, there are many strategies that can be used to achieve that integration, providing large quantities of fuel while enhancing ecosystem services and addressing socioeconomic needs. Central to all of these strategies are embedded concepts of multifunctional landscapes, integrated landscape design, and resilience in the face of changes yet to come.

13.7 Recommendations

Given the potential changes in land use identified in this chapter and other reports and the impact bioenergy may have on natural forests and agricultural lands, land-use planning should be on the national development agendas before embarking on large-scale bioenergy production systems. Successful implementation of such plans will require clear sustainability metrics and monitoring programs, stable land tenure, and effective local and national governance.

In drawing national and regional integrated forestry, agriculture and bioenergy policies it is imperative to address the underlying causes of land use conversion and unsustainable resource development. Issues to be included in such multi-sector policies include full valuation of forest goods and services, opportunity costs of forestland conversion and alternative cropping systems, governance and law enforcement, institutional capacities, and safeguarding land tenure and other rights of local communities.

Another venue to strengthen cross-sector forestry and agriculture policies and aligning implementation pertaining to bioenergy is to incorporate recent initiatives such as REDD+ programs, Green Economy and Climate-Smart Agriculture into national development strategies.

Tree plantations and agroforestry systems which incorporate biofuel production could be profitable for both domestic use and as out-growers for industrial enterprises, but require that land tenure, access rights and sustainability requirements are all treated unambiguously in both law and in practice.

Integrated forestry, agriculture and bioenergy policies should be based on detailed land suitability and availability assessments (Schoneveld 2010). Furthermore, land availability for biofuel expansion based on agro-ecological zoning would avoid undue competition for land.

Intergovernmental agreements and conventions on climate change, biodiversity and desertification among others, address agriculture, forestry and bioenergy directly and indirectly, but generally consider these as independent rather than integrated sectors. Therefore, internationally negotiated and ratified instruments are needed that systematically address integrated forestry/agriculture/bioenergy interactions.

13.8 The Much Needed Science

A wealth of anecdotal and site-specific scientific evidence demonstrates that diverse agricultural and forest systems, and especially coupled systems that include herbaceous and woody species, can be highly productive in meeting human needs. But a far smaller number of cases or research reports document this productivity through quantitative, independent assessments across multiple systems. As a result, the mechanisms and magnitude of the productivity of diverse, integrated systems relative to uniform monocultures remain contested. Fundamental research on ecological principles, along with systems research on specific mixtures and integration strategies in different socio-ecological contexts, is needed to quantify the costs, advantages, and tradeoffs of integration. These studies should be done with a common set of metrics, so that valid comparison to other studies in other regions is possible, and eventually so that a meta-analysis of the results can be made. Dale et al. (2013) offer a good starting point for such a common set of metrics.

While quantitative and comparable systems and sustainability studies are needed for integrated crop and forest systems in general, this need is particularly strong where bioenergy is concerned. Bioenergy feedstocks and processes offer opportunities to greatly increase the internal energy and nutrient recycling in such systems through residue use, nutrient recovery, and increased water use efficiency. The tools of industrial ecology can provide insight into these opportunities as well as challenges, by expanding the system boundaries beyond individual fields and farms to communities and processing facilities.

Finally, there is a tremendous need for social science research into the preconditions, processes, and governance required for these integrated systems to grow and thrive. Challenges are often not technical, but relate to educational resources, social and cultural norms, private and public financing, infrastructure, markets, policy and governance. The sustainability transitions literature (Hinrichs 2014) offers important insights into these processes and the challenges of getting on and staying on a trajectory toward sustainable food, energy, and landscapes.

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