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Biofuel Feedstocks: The Risk of Future Invasions

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Introduction

In an effort to decrease greenhouse gas emissions, expand domestic energy production, and maintain economic growth, public and private investments are being used to pursue dedicated feedstock crops for biofuel production.

In an effort to decrease greenhouse gas emissions, expand domestic energy production, and maintain economic growth, public and private investments are being used to pursue dedicated feedstock crops for biofuel production. Unlike food crops grown for grain-based ethanol (e.g., corn), which require high inputs of fertilizers and pesticides and typically are grown on prime agricultural land, proposed lignocellulose-based energy crops (e.g., switchgrass) typically have a neutral or negative carbon budget, require relatively few economic or environmental inputs, and can be cultivated on marginal, lower-productivity land. Thus, a rapidly growing industry related to crop selection, cultivar improvement, and conversion technologies is emerging.

From an agronomic perspective, certain nonnative grasses are ideal for use as feedstock crops.

A variety of plant species, including grasses, herbs, and trees, are being considered for use as dedicated biofuel crops across much of the United States (Figure 1). The leading candidates for lignocellulose-based energy, however, are primarily rhizomatous (i.e., having belowground vegetative reproductive structures) perennial grasses. Most of these grasses are not native to much of the region where production is proposed (Lewandowski et al. 2003). From an agronomic perspective, their life history characteristics, rapid growth rates, and tonnage of biomass produced by these nonnative grasses make them ideal feedstock crops.

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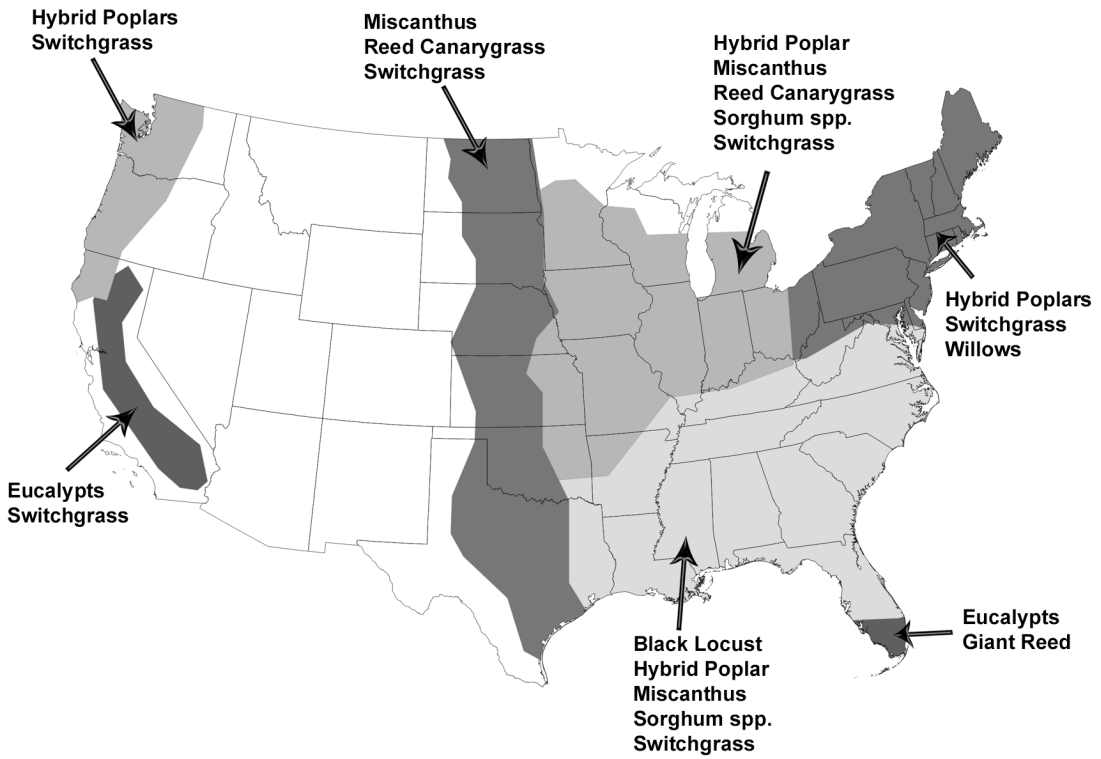

Figure 1. Lignocellulose-based biofuel feedstocks and their potential region(s) of cultivation. This map represents only a small portion of the possible taxa for feedstock purposes. Many other nonnative crops are being considered in the United States, especially for biodiesel; for example, camelina (*Camelina sativa*) in the northern Great Plains and jatropha (*Jatropha curcas*) in Hawaii. (Adapted from U. S. Department of Energy 2007.)

Several candidate biofuel feedstock species being considered for U. S. commercial production are invasive pests elsewhere.

Unfortunately, several of the candidate biofuel feedstock species being considered for commercial production in the United States are invasive pests (i.e., nonnative species causing economic or environmental damage) in other regions where they have been introduced. Their invasiveness is attributed mainly to their life history characteristics and rapid growth rates. The combination of being nonnative and possessing weedy characteristics, along with their potential scale of cultivation, presents a significant risk that biofuel crops could escape cultivation and potentially damage surrounding ecosystems. Biofuel crops likely will be cultivated on lands surrounded by sensitive forest, prairie, desert, and riparian areas, as well as by rangelands and agricultural commodities.

Introduction and development of biofuels should be conducted in a manner that will result in minimal risk.

Breeding and genetic engineering for enhanced environmental tolerance (e.g., drought tolerance), increased harvestable biomass production (e.g., lower root-to-shoot ratio), and enhanced energy conversion through fermentation (e.g., lower lignin content) may have unexpected ecological consequences outside the agronomic framework. The potential societal benefits of a biologically based energy supply are great, but the introduction and development of biofuel crops should be conducted to minimize the risk of these proposed feedstock species escaping cultivation and causing economic or environmental damage.

Table 1. Comparison of traits that characterize an ideal agronomic crop but also characterize many invasive plants. Comparison among common (nonweedy) agronomic crops, potential biofuel feedstocks, and an invasive species originally introduced for agronomic purposes (e.g., forage)

Traits	Nonweedy agronomic crops		Potential biofuel feedstocks		Invasive species with agronomic origin
	Corn	Soybean	Switchgrass	Giant Reed	Johnsongrass
Perennial	-	-	X	X	X
C_4 photosynthesis	X	-	X	-	X
Rapid establishment rate	X	X	X	X	X
Long canopy duration	X	-	X	X	X
Grows at high densities	-	-	X	X	X
Tolerates water stress	-	-	X	-	-
Tolerates low fertility soils	-	-	X	X	X
Tolerates saline soils	-	-	*	*	-
Re-allocates nutrients to perennating structures in fall	-	-	X	X	X
No major pests/diseases	-	-	X	X	X

*Potential trait through biotechnology

The objectives of this Commentary are to describe the potential risk of dedicated lignocellulose biofuel feedstocks becoming weedy or invasive and to provide a process to quantify and, subsequently, minimize this risk.

Similarities between Agronomic and Invasive Traits

Biofuel crops are being selected, bred, and engineered to exhibit desirable agronomic traits, many of which also typify much of the nonnative flora invading native ecosystems.

For dedicated biofuel crops to be economically viable, they should require few inputs of water, nutrients, pesticides, and fossil fuels while producing large annual yields of aboveground biomass from a single planting of a perennial species. Agronomic trials conducted in Europe and the United States have identified several candidate species for biofuel production, many of which are fast-growing, rhizomatous perennial grasses. Biofuel crops are being selected, bred, and engineered to exhibit the desirable agronomic traits shown in Table 1, which characterize a low-input, high-yielding feedstock crop able to be cultivated on marginal, low-productivity land.

Many of these desirable agronomic traits, however, also typify much of the nonnative flora invading native ecosystems globally (Raghu et al. 2006). Numerous examples exist of nonnative species being introduced for agricultural purposes—especially as livestock forage and for horticultural use—that escape the confines of agricultural production and cause unforeseen ecological damage (e.g., johnsongrass: *Sorghum halepense*; kudzu: *Pueraria montana* var. *lobata*). Unlike most major crops (e.g., corn, soybeans, small grains) that typically are introduced species requiring irrigation, nutrients, and pesticides to survive, biofuel feedstocks are being selected

A balance must be struck between designing biofuel feedstock crops to require minimal inputs yet preventing them from surviving outside the cultivated environment.

from taxa that produce highly competitive stands that thrive with minimal human intervention. Therefore, a balance must be struck between designing biofuel feedstock crops to require minimal inputs and yet preventing them from surviving outside the cultivated environment. (Table 1 provides a comparison of traits among nonweedy agronomic crops, potential biofuel feedstocks, and an invasive species originally introduced as forage.)

Despite numerous attempts, no master list of traits has been compiled that exemplifies all invasive plant species—because of their varied life forms, environs invaded, and interactions of plant traits and habitat attributes—thus precluding easy identification of future invaders. Ample evidence does exist, however, that nonnative species present a high risk of becoming invasive when they possess few resident natural enemies, exhibit rapid establishment and growth rates, tolerate broad environmental variation, and produce large quantities of easily dispersed propagules (i.e., seeds or other vegetative reproductive structures).

Biofuel feedstock propagules will be introduced in vast quantities for commercial-scale production, with the risk of escaping cultivation being proportional to the propagule pressure (i.e., the rate at which a species is introduced into an ecosystem) on the surrounding environment. To aid in efficient energy conversion, biofuel feedstocks typically are harvested after senescence in the field, usually in late fall. By this time the feedstocks have produced seed, which are then at risk of being dispersed unintentionally during harvest and transport to energy conversion facilities. Through planting, harvesting, and transporting of biofuel crops, there exists a significant risk of accidental introduction to susceptible native habitats and agricultural fields.

How Will Genetic Modification Affect Potential Invasiveness?

Dedicated energy crops are being modified to have drought or salt tolerance and enhanced nutrient-use efficiency, affording cultivation with limited human intervention on marginal lands that possess few resources.

Many major crops have been genetically modified through traditional breeding or molecular techniques to possess disease or herbicide resistance and to produce high yields (of seeds or fruits, typically) with little consequence to surrounding ecosystems. Most modified crops have not become pests because of their inability to survive without cultivation—likely a result of their agronomically desirable traits of genetic uniformity for ease of harvest, high nutrient requirements, and low seed dormancy, among others. Dedicated energy crops, however, are being modified to have drought or salt tolerance and enhanced nutrient-use efficiency, affording cultivation with limited human intervention on marginal lands that possess few resources. This enhancement in environmental tolerance likely will increase the risk of escape from cultivation and invasion into surrounding environments. Similarly, enhancement of aboveground biomass production via biotechnology could allow such cultivars to be more competitive with native vegetation or other cultivated crops.

Sterile cultivars can decrease the likelihood of biofuel species escaping from production fields.

Conversely, as exemplified by the sterile biofuel crop miscanthus (*Miscanthus* × *giganteus*), a lack of seed production can decrease the risk of escaping cultivation dramatically (Lewandowski et al. 2000). Despite one of the parent species of this hybrid (*Miscanthus sinensis*) being widely recognized as invasive in the United States and elsewhere, the sterile hybrid has not been reported to escape cultivation.

Sterile cultivars can decrease the likelihood of biofuel species escaping from production fields. The value of this mitigation technique must be considered for each

taxon, however, because many important invasive species fail to produce fertile seed, yet they are able to colonize vast regions and inflict economic and ecological damage (e.g., giant reed: *Arundo donax* as shown in Figure 2).

Figure 2. Giant reed (*Arundo donax)* can reach 30 feet in height.

Like nonnative species, even native plants—if modified—would pose an unknown risk of becoming invasive.

Genetic modification can change the phenotype or physiology of a taxon sufficiently to lead to alterations in plant-plant interactions and ecological functions. Thus, it is important to recognize that, like nonnative species, even native plants—if modified—would pose an unknown risk of becoming invasive. For example, switchgrass (*Panicum virgatum*), the leading feedstock candidate in the continental United States, is native to most of North America east of the Rocky Mountains. Its general phenotype and overall yield, however, are highly variable depending on the location of cultivation and the latitude of origin (Parrish and Fike 2005). Although genetic modification of switchgrass could produce higher-yielding cultivars or enhanced drought tolerance, this process would result in further unpredictability concerning ecological interactions and consequences. Even within the native range of the species, modified cultivars should be treated as nonnative genotypes.

Mitigating Future Invasions

Federal and state energy goals (e.g., the Biofuels Initiative and the California Executive Order S-06-06, respectively), along with economic and environmental incentives for cultivating feedstock crops for energy production, may be too great to prevent the widespread introduction of nonnative species for biofuel purposes. But nonnative species and non-wild-type native species (i.e., native species after genetic modification) should be introduced in a responsible manner that mitigates the risk of escaping cultivation and invading sensitive or managed ecosystems. Genetically modified crops and biological control agents currently are required to undergo extensive screening before being introduced commercially and could serve as models

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for the regulation of biofuel crops. The risk of each feedstock cultivar or genotype's escaping cultivation, as well as the potential ecological ramifications, should be understood before commercialization. The use of pre-introduction evaluations such as the following could aid in that understanding.

- Weed Risk Assessment (WRA) evaluations—protocols based on target species biology, ecology, climatic requirements, and introduction history—of each potential genotype targeted for cultivation within a particular region (See, for example, Barney and DiTomaso forthcoming)
- Climate-matching analysis to determine regions of agronomic suitability and identification of regions climatically suitable to a potential invasion
- Evaluation of the cross-hybridization potential of the biofuel crop with related species and other closely related taxa to assess the risk of genetic invasion
- Determination of the susceptibility of native and managed ecosystems to introduction of seeds or vegetative fragments of the biofuel feedstock
- Multiyear studies of competitive interactions between biofuel crops and native or agronomic species within susceptible ecosystems
- Establishment of pre-introductory management protocols that demonstrate eradication of proposed feedstocks

Many of these evaluations could be performed in parallel with typical agronomic yield trials, affording quantification of ecological risk while informing feedstock suitability and management. Pre-introduction screening results could provide information to shape policy regarding commercialization, regulation, and government subsidies and crop insurance.

Policy Implications

Currently, the introduction of nonnative species for horticultural or agronomic purposes is not regulated unless the taxa are on state or federal lists of noxious weeds.

Currently, the introduction of nonnative species for horticultural or agronomic purposes is not regulated unless the taxa are on state or federal lists of noxious weeds. Therefore, stewardship of feedstocks will be entrusted to those who breed and commercialize crops to introduce biofuels that pose a minimal risk of causing unintentional economic or ecological damage. Mechanisms for such responsible introductions could be modeled on the horticulture industry in which local and regional organizations cooperate with the nursery industry to restrict the sale and distribution of species and cultivars that pose quantifiable threats to native species and ecosystems. Additionally, producers who commercialize and produce biofuels could adopt a voluntary code of conduct requiring the pre-introduction evaluations outlined previously.

Local, state, or national policy adoption of weed risk assessments would benefit both society and breeders.

Various governments currently are adopting pre-introduction, science-based risk assessment tools to estimate quantitatively the risk of a nonnative species becoming invasive. These WRA protocols are highly accurate in predicting major invasive species and benign nonnatives and are moderately accurate for minor invasive species (Pheloung, Williams, and Halloy 1999). Local, state, or national policy adoption of WRAs would benefit both society and breeders, who could subsequently target traits contributing to invasiveness (e.g., seed production) and avoid releasing cultivars with these characteristics. Weed risk assessment adoption is a robust first step in mitigat-

ing the introduction and commercialization of invasive biofuel feedstocks (Barney and DiTomaso forthcoming).

The federal government has initiated a policy necessitating documentation that experimental biofuel feedstocks pass certification to ensure that they pose no more than a minor threat of becoming a noxious or invasive weed within the target region. This policy would preclude government subsidization or crop insurance without a thorough ecological analysis and risk assessment, thereby decreasing the probability of future invasions.

Conclusion

Ideally, biofuel feedstocks should be propagated easily in highly managed agricultural systems but should not be capable of surviving outside of such cultivation.

The hurried pace with which biofuel crops currently are being sought to replace fossil fuels likely will usher in a novel industry of biologically based energy. This industry will be sustained mainly with nonnative perennial species chosen for their rapid growth rates, annual production of large aboveground biomass, and low economic and environmental inputs. Ideally, biofuel feedstocks should be propagated easily in highly managed agricultural systems but should not be capable of surviving outside of such cultivation. This circumstance is true for nearly all major crops currently grown in the United States, including rice, wheat, corn, soybean, cotton, tomato, and alfalfa.

Similar expectations should apply to biofuel crops. Without this expectation, the benefits of dedicated biofuel feedstock production may be offset by far greater economic and ecological damage caused by their invasion into sensitive natural ecosystems, agricultural production systems, drainage and irrigation canals, and other managed habitats. Although introducing some plant species as biofuel sources may be safe and beneficial to society, the environmental and ecological risks associated with their potential escape and invasion into natural and managed systems must be evaluated along with the agronomic and economic benefits.

Literature Citations

Barney, J. N. and J. M. DiTomaso. Forthcoming. Non-native species and bioenergy: Are we cultivating the next invader? *BioScience*.

Lewandowski, I., J. C. Clifton-Brown, J. M. O. Scurlock, and W. Huisman. 2000. Miscanthus: European experience with a novel energy crop. *Biomass Bioenergy* 19:209–227.

Lewandowski, I., J. M. O. Scurlock, E. Lindvall, and M. Chistou. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the U.S. and Europe. *Biomass Bioenergy* 25:335–361.

Parrish, D. J. and J. H. Fike. 2005. The biology and agronomy of switchgrass for biofuels. *Crit Rev Plant Sci* 24:423–459.

Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *J Environ Manage* 57:239–251.

Raghu, S., R. C. Anderson, C. C. Daehler, A. S. Davis, R. N. Wiedenmann, D. Simberloff, and R. N. Mack. 2006. Adding biofuels to the invasive species fire? *Science* 313:1742.

U. S. Department of Energy, Office of Science. 2007. Genomics: GTL. *Systems Biology for Energy and Environment*, http://genomicsgtl.energy.gov/biofuels/ (3 August 2007)

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