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Invasive plant species as potential bioenergy producers and carbon contributors

Stephen L. Young, Gayathri Gopalakrishnan, and Deepak R. Keshwani

CURRENT CELLULOSIC BIOENERGY SOURCES

In the United States, bioenergy sources are being investigated in an effort to reduce dependence on foreign oil and the associated risks to national security and climate change (Koh and Ghazoul 2008; Demirbas 2007; Berndes et al. 2003). Multiple sources of renewable plant-based material have been identified and include agricultural and forestry residues, municipal solid waste, industrial waste, and specifically grown bioenergy crops (Demirbas et al. 2009; Gronowska et al. 2009). These sources are most commonly converted to energy through direct burning, conversion to gas, or conversion to ethanol. Annual crops, such as corn (*Zea Mays* L.) and sorghum grain, can be converted to ethanol through fermentation, while soybean and canola are transformed into fatty acid methyl esters (biodiesel) by reaction with an alcohol (Demirbas 2007). Perennial grasses are one of the more viable sources for bioenergy due to their continuous growth habit, noncrop status, and multiple use products (Lewandowski et al. 2003). In addition, a few perennial grass species have very high water and nutrient use efficiencies producing large quantities of biomass on an annual basis (Dohleman et al. 2009; Grantz and Vu 2009).

Cellulosic bioenergy research is widespread throughout the country (figure 1) and has resulted in a proliferation of studies examining switchgrass (*Panicum virgatum* L.) in cropping systems (Sanderson et al. 2006). The major focus of current switchgrass research is on production and establishment (Bhandari et al. 2008;

Brenner and Moore 2008; Butler et al. 2008; West et al. 2008), with other studies on the effects of switchgrass growth on carbon and nitrogen cycles (Parrish and Lemus 2008), diversity of species mixes containing switchgrass (Staggenborg and Prophet 2008), and the breeding/genetics of switchgrass biotypes (Samuels et al. 2008). In addition to switchgrass, research in the United States is being conducted on many other cellulosic crops, such as *Miscanthus giganteus*, hybrid poplar (*Populus* hybrids), and reed canarygrass (*Phalaris arundinacea* L.) (Sanderson and Adler 2008). To date, little research has been conducted on existing (noncultivated) bioenergy sources (e.g., invasive plant species) from noncrop agricultural land (e.g., marginal and riparian areas).

INVASIVE PLANT SPECIES ESTABLISHMENT

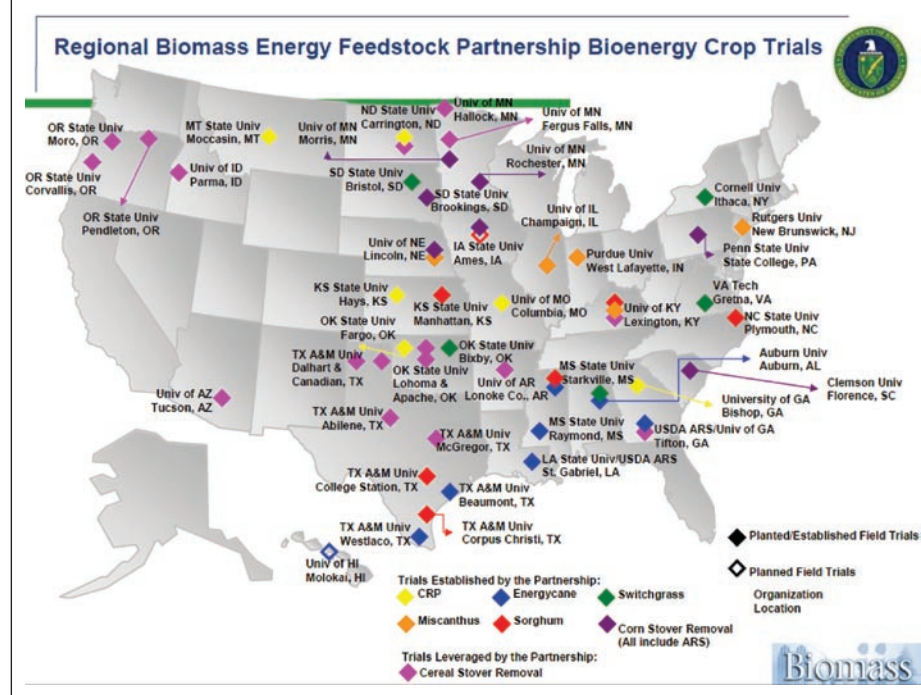
Nonnative invasive plant species have become established in most North American landscapes. In the western

United States, invasive plant species dominate many of the major river systems, including the Colorado (saltcedar [*Tamarisk* spp.]), San Joaquin (giant reed [*Arundo donax* L.]), and Rio Grande (perennial pepperweed [*Lepidium latifolium* L.]) river systems (Ringold et al. 2008; Shafroth et al. 2008; Spencer et al. 2008; Stromberg et al. 2007; Nagler et al. 2005; Renz and Blank 2004). Across the United States and Canada, purple loosestrife (*Lythrum salicaria* L.) and nonnative common reed (*Phragmites australis* [Cav.] Trin. ex Steudel), hereafter referred to as common reed, have been more widespread, invading and establishing in most of the major river systems (Meyerson et al. 2010; Carlson et al. 2009; Miller et al. 2009; Knezevic et al. 2008; Laba et al. 2008; Whyte et al. 2008; Denoth and Myers 2007; Anderson et al. 2006; Lindgren 2006; Herrick and Wolf 2005; Knezevic et al. 2004).

A case in point is the Platte River that bisects the state of Nebraska and is currently infested with several invasive plant

Figure 1

Locations for bioenergy feedstock research in the United States (USDOE EERE 2008).



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species (Narumalani et al. 2009; Wilson 2009; Wilson and Bernards 2009; Hoffman et al. 2008; Knezevic et al. 2008; Wilson and Knezevic 2007; Roeth et al. 2003). Common reed, one of the most dominant and prolific biomass producers, has established in the Platte River and throughout much of the North American continent (figure 2). It was first introduced to North America in the 1800s and is now established in all states, except Alaska and Hawaii, occurring mainly in or near waterways and riparian areas. Common reed grows perennially with stem densities greater than 150 stems m^{-2} (14 stems ft^{-2}), canopy that routinely reaches 3 m (9.8 ft) or more (Rapp and Knezevic 2010), and yields of up to 10 Mt ha^{-1} (5 tn ac^{-1}) (Bjork and Graneli 1978). In 2008, the heaviest populations of common reed in Nebraska could be found starting in North Platte along the Platte River and stretching over 400 km (250 miles) east to the Missouri River (figure 2) (Knezevic et al. 2008).

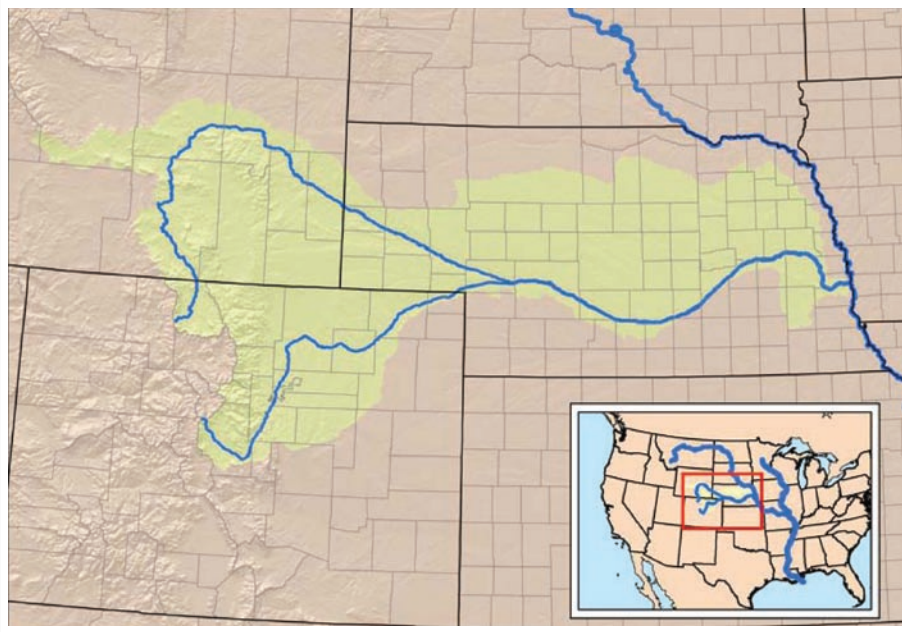
INVASIVE PLANT SPECIES IMPACTS

The losses associated with established invasive plant species are substantial, with estimates of almost \$120 billion per year in the United States (Pimentel et al. 2005). Of the 25,000 nonindigenous plant species, the cost to control nonnative aquatic invaders is over \$100 million per year. Purple loosestrife alone accounts for annual control costs and forage losses of close to \$50 million (Pimentel et al. 2005). In addition to the direct losses to agriculture, forestry, recreation, and threats to human health from invasive plant species, nontangible items, such as biodiversity, ecosystem services, and aesthetics are also impacted by invasive plant species (Pejchar and Mooney 2009). Recreational access and aesthetic qualities can be severely hampered by the establishment of invasive plant species (Boylen et al. 2006; Henderson et al. 2006; Colautti et al. 2006).

The establishment of invasive plant species can have many negative effects on the native plant species and environmental conditions. Mortenson et al. (2008) found that the presence of saltcedar indirectly impacts the hydrologic conditions in Grand Canyon National Park through the selective use of native woody competitors

Figure 2

Map of the Platte River watershed, including the North Platte and South Platte tributaries, based on US Geological Survey data (Courtesy of Karl Musser, Geographer/Web Developer, Paradigm Systems GIS Inc., Bowie, Maryland).



by beavers. The establishment of invasive plant species can affect surface water flow in arid and semiarid climates. Reed et al. (2005) and Murphy et al. (2008) show that native grasslands have less runoff due to high amounts of litter, dead standing herbage, and ground cover, which is in direct contrast to the annual grass dominated landscapes of the Pacific and Intermountain regions of western United States. Other studies give evidence supporting the deleterious effects of invasive plant species establishment on plant diversity (Reinhart and Callaway 2006; Dukes 2001; Mullin 1998) and soil nutrient cycles (Weidenhamer and Callaway 2010; Raizada et al. 2008; Ehrenfeld 2003).

Individual plant species can modify soil nutrients through multiple processes and hence impact the global biochemistry. As plants take up nutrients for growth, the incorporation of nutrients into stable organic material results in the sequestration of important elements, such as carbon. However, they also impact belowground mineral pools through chemicals exuded from the roots (exudates), decomposition of leaf litter of differing chemical quality, and nutrient and carbon mineralization rates (Tilman et al. 1997; Hooper and

Vitousek 1998; Ehrenfeld 2003; Chapin et al. 2000).

Prior research has indicated that invasive plant species may alter nutrient cycles in ways that are different from native species (Weidenhamer and Callaway 2010). Allison and Vitousek (2004) showed that the leaf areas, growth rates, and leaf nutrient concentrations are significantly higher in invasive plants compared to native species and these traits could increase rates of litter decomposition and nutrient cycling. Ehrenfeld (2003) and Wolfe and Klironomos (2005) indicated that invasive plant species often increase carbon inputs into the ecosystem as a result of greater primary production and thus alter processes governing carbon and nutrient cycles. Changes in plant species also affect the soil microbial communities and hence the carbon and nutrient cycles (Kourtev et al. 2002; Ravit et al. 2006). Further, Hamilton and Frank (2001) have suggested that grazing of invasive plant species by herbivores influences root exudates and hence soil carbon structure. Similar results may be obtained if invasive plant species, such as common reed, are harvested to produce bioenergy. Much of the research on invasive plant species to date has been

at the field scale, when the plant is already present in the ecosystem as an invasive. Effects of the invasive species on native species, growth, harvesting, and impact on greenhouse gas emissions and hydrology have received limited research.

INVASIVE PLANT SPECIES BIOENERGY POTENTIAL

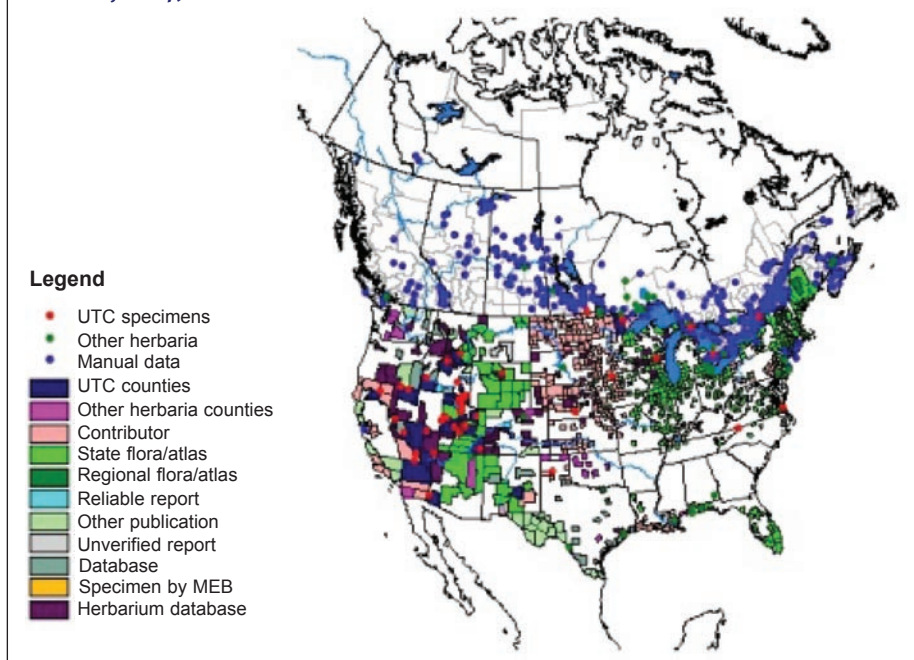
The widespread distribution and high rate of biomass production (10 to 30 oven dry Mt ha⁻¹ [5 to 15 tn ac⁻¹]), particularly for species located near water sources (e.g., riparian areas, lakes, and coastal bodies), make invasive plant species, like common reed, a viable bioenergy source (figure 3). This fact has largely been ignored by many biofuel advocates and disputed by invasion biologists (Davis et al. 2008; Simberloff 2008).

In the near future, most of the biomass for energy is predicted to come from urban, forest, and agricultural residues, particularly from cereal grains or from crops grown specifically for biomass-based energy production (Perlack et al. 2005; USDOE EIA 2010). While crop residues are of interest because they are produced in major regions across the United States and are available at reasonable prices (Graham et al. 2007), invasive plant species are free for the taking and grow everywhere, including marginal lands that are currently under consideration for producing crop residues (Brown 2007; Tilman et al. 2006).

When consideration is given for invasive plant species as bioenergy sources, most opponents raise concerns about anthropogenic movement (i.e., transportation) and establishment (i.e., crops) of invasive plant species (Cousens 2008; Simberloff 2008). In a forum paper by Barney and DiTomaso (2008), the words ‘cultivation’ and ‘crop’ were used repeatedly to describe the threats that nonnative invasive species pose when being considered for use as a bioenergy source. The discussion of invasive plant species solely in the context of cropping systems fails to consider the potential for using existing stands of invasive plant species as a bioenergy source. Ideally, biofuel crops should be propagated in containable systems, and fundamental research needs to be conducted to identify traits that reduce the risk of biological invasion (DiTomaso

Figure 3

Common reed distribution in the United States and Canada (Utah State University 2007).



et al. 2010). Unfortunately, the ideal system does not exist, but what does exist is increasing populations of invasive plant species that are expanding their range and extending their devastating effects on the environment and economy.

What is noticeably absent in the literature are studies on the use of existing (i.e., noncultivated) invasive plant species populations as bioenergy sources. This approach does not advocate the cultivation or proliferation of new or novel crops that are nonnative invasive species or possess invasive characteristics. Studies continue to document increasing rates of spread and distribution of invasive plant species (Duncan et al. 2004) with little evidence of control efforts that have significantly or permanently reduced large infestations of invasive plant species. A management approach that results in the containment or reduction of existing stands of invasive plant species is a main tenant founded in the principles of weed science (Radosevich et al. 1997; Ross and Lembi 1985) and is fully supported by the authors of this paper.

The literature is clear that significant amounts of biomass can be produced by perennial plant species, native and nonnative (Sanderson and Adler 2008). However,

there are no studies that have investigated how invasive plant species might be managed in a total systems approach that seeks to reduce invasive plant species in the environment and supply either a liquid, drop-in biofuel or a dry matter source for facilities with biomass heating and cooling systems.

USE OF INVASIVE PLANT SPECIES FOR BIOENERGY

There is an absence of scientific studies on the use of invasive plant species in biomass heating and biomass furnace technology. Wood products are used in biomass burning facilities. Wood is readily converted to a useable form for burning in boilers by chipping, shredding, or pelleting, which also eases the transport and storage requirements. In parts of the United States, native perennial grasses are grown for use as pellets in wood stoves and wood burning facilities (Samson et al. 2005). While the harvesting of native perennial grasses in an agricultural setting is different than harvesting of invasive plant species in noncrop areas, the process is similar and worth consideration.

Existing knowledge on ethanol production potential of invasive plant species

(e.g., common reed) is limited. Szijarto et al. (2009) reported 83% cellulose conversion of common reed into soluble sugars, and after fermentation, final ethanol yields were reported to be 73% of theoretical maximum. Sathitsuksanoh et al. (2009) used a solvent-based fractionation approach to achieve similar yields of fermentable sugars from common reed. While these results are promising, the pretreatment methods are reported to be prohibitively expensive due to chemical costs (Sun and Cheng 2002; Alvira et al. 2010).

THE FUTURE OF INVASIVE PLANT SPECIES BIOENERGY

Among recent advances in developing cellulosic and noncellulosic biofuel sources, corn, switchgrass, and others (e.g., camelina, canola) have risen to the top. In surveying the landscape, a potentially promising new area of bioenergy production exists—invasive plant species. The addition of invasive plant species as a bioenergy source will help to diversify the nation's energy dependence and help in the reduction of the negative environmental and social impacts from energy crop production. In addition, belowground carbon stores may provide an opportunity to reduce the impacts associated with global climate change.

In the agriculture sector, harvesting equipment is well advanced for facilitating efficient crop production on both small and large scales. In noncrop systems, the number of limitations and lack of need have slowed the progress of equipment development for biomass harvesting (Graneli 1984). The lack of economic return is an important reason for less intensive management in noncrop areas. With new markets emerging for cellulosic energy sources and advances in equipment technology, this increased incentive could help improve the level of management of invasive plant species in noncrop areas and subsequent harvest or removal of excess biomass.

Using invasive plant species in bioenergy facilities would provide enticing opportunities for land managers and business developers. Since the primary focus of most invasive plant species management is on control of unwanted vegetation, the

massive amounts of biomass from high cellulosic plants creates a challenge for disposal. Research has shown that piling or dispersing cut portions of many woody and herbaceous invasive plant species can result in the reestablishment by new plants from propagule segments (Boose and Holt 1999; Decruyenaere and Holt 2001). With advances in processing equipment, invasive plant species biomass could be processed into pellets for transporting to facilities that burn biomass or convert biomass to liquid biofuels. The processing of invasive plant species into a useable form (i.e., pellets) that does not promote the spread or introduction of unwanted vegetation minimizes the risks of environmental contamination and provides an economic opportunity for business development in rural communities.

While corn and switchgrass are the leading plant candidates for biofuel production, they may not be the most sustainable. Alternatively, the removal of existing invasive plant species biomass and processing into pellets for combustion or liquid fuel conversion maybe more sustainable as it would comply with the US Executive Order 13112 on invasive species (Clinton 1999), support climate change initiatives (Crowl et al. 2008), and expand economic opportunities in rural areas by helping fulfill the mandate by the US Renewable Fuels Standards (USDA 2010).

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