



WILLOW BUFFERS IN AGRICULTURAL SYSTEMS: LINKING BIOENERGY PRODUCTION AND ECOSYSTEM SERVICES

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WILLOW BUFFERS IN AGRICULTURAL SYSTEMS: LINKING BIOENERGY PRODUCTION AND ECOSYSTEM SERVICES

By,

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INTRODUCTION: MULTIFUNCTIONAL LANDSCAPES

The production and consumption of food, energy, and water are inextricably linked. With agricultural systems contributing high levels of nutrients into ground and surface water systems, agriculture poses both human health and environmental risks downstream of these non-point sources (Zumpf et al. 2017). This project was designed to develop and prove concepts supporting multifunctional landscapes, which address multiple problems regarding food, energy, and water. The benefits of multifunctional landscapes over simplified landscapes (i.e., crop monocultures) include the ability to address these multiple societal challenges simultaneously by incorporating components that can perform multiple services (Ssegane et al. 2015).

SHRUB WILLOW BUFFERS

Integration of shrub willow into an agricultural landscape can serve dual purposes of providing ecosystem services while producing cellulosic biomass feedstock for bioenergy and other applications (Zumpf et al. 2017). Landscape management that incorporates buffers of biomass crops into traditional grain cropping systems can address multiple problems simultaneously. Willow, a perennial crop, can reduce the amount of nutrients that leach from agricultural fields into surface water systems, improve soil health, and increase grower's profits. This environmental application explores the feasibility of utilizing shrub willow buffers within

and along the edges of corn fields (Figure 1). This buffer system achieves nutrient reduction goals while producing biomass feedstocks. The study site was located in central Illinois, representing a typical non-tiled, intensively managed Midwestern agricultural landscape.



Figure 1. Third-year shrub willow (*Salix miyabeana* 'SX61') compared to corn (*Zea mays* L.) in early August on marginal lands in Fairbury, IL.

Willow, Poplar, and Agriculture

The use of willow or poplar buffers within an agricultural landscape is not a new concept. As with any production system, it is important to select the right crop for the right job and for the right location. Due to their wide genetic base, both have a range of ideal phenotypic and functional qualities, such as high nutrient and water uptake, tolerances to a variety of environmental conditions, and high biomass production. Potential producers are encouraged to contact local Extension agencies or other organizations that have experience with willow or poplar to assist in designing a production landscape that will work with the growers' needs. Cultivar type, management practices, including site preparation and annual maintenance, and landscape position, including drainage, soil type, topography, and water table depth, play important roles in buffer efficiencies and therefore need to be taken into consideration when employing willow or poplar for this type of practice.

RESEARCH SITE

The willow buffer research was conducted on a field site that is part of the well-studied Indian Creek Watershed in Central Illinois, located at the headwaters of the nitrate-impaired Vermillion River Watershed. The management practices (fertilizer and tillage) utilized on this field site for grain crop production are representative of much of the agricultural landscape that stretches across the Midwestern United States. The site is a 6.5-ha (16.1-acre) continuous corn rotation field with 0.8 ha (2.0 acres) of willows (as 0.2-ha [0.5-acre] plots). Willows were planted in the spring of 2013 with a step planter at a planting density of 15,300 cuttings per ha (~6,000 cuttings per acre) into a grass cover crop using a traditional double row planting system (150-cm [4.9-ft] spacing between double rows, 75-cm [2.5-ft] between rows, and a 60-cm [2.0-ft] in-row spacing). Weeds and understory were managed by mowing due to foliar damage by herbicide application in the first year (Zumpf et al. 2017).

Two types of willow production were compared (Figure 2). The first was willow grown along the field edge on non-marginal land (or land suitable for crop cultivation—northern plots). The second was an

in-field buffer of willow planted downslope from corn on marginal land (or land underproductive for grain crop—southern plots) susceptible to nutrient leaching. The placement of the buffers on the field allowed for leached nutrients from upslope corn (fertilized with 247 kg N per ha, per yr [221 lb N per acre, per year]) to serve as the fertilizer source for willow biomass production (passive recovery of nutrients) and thereby reducing nutrient leaching into subsurface waters and the nearby Indian Creek (which lies directly to the west of the field—not shown in Figure 2).

Willows were not directly fertilized due to their lower nutrient requirements as compared to corn (all corn was fertilized). Willows can also tolerate lower soil nutrient conditions by expanding their root system, which is ideal in this case for scavenging nutrients. Additionally, since willows are harvested after corn, they need less headland space (uncultivated field border), allowing more land to be maintained for corn and willow production.

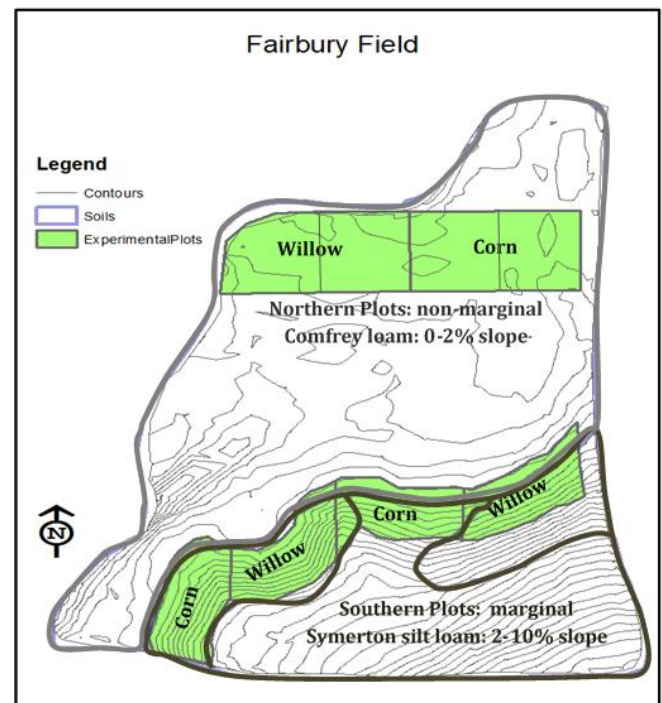


Figure 2. Plot layout of the field site in Fairbury, IL, denoting plot boundaries, soil types, topography, and average slope. The non-marginal land including northern plots have an elevation range of 204–205 m (670–675 ft) above mean sea level (MSL), southern plots range from 205–207 m (675–680 ft) MSL, and land to the south of the southern plots range from 207–210 m (680–690 ft) MSL.

The site has been continuously monitored for 6 years, pre- and post-willow introduction.

MEASURING ECOSYSTEM SERVICES

Nitrogen Reduction

Nitrate leaching (where $\text{NO}_3 + \text{NO}_2\text{-N}$ is referred to as nitrate for the purposes of this environmental application) from corn production and its subsequent reduction through willow uptake was assessed within plots via soil water monitoring as well as at the edge of field through groundwater monitoring. In 2015, after only two years of growth, willows were found to significantly reduce nitrate leachate from corn into soil water by 70% and more significantly, by the third year (Figure 3). As the willow’s aboveground and belowground biomass increased, leachate reduction on average was 88% by 2016 (Zumpf et al. 2017). This suggests that as the willows’ belowground biomass continues to grow until peak maturity, nitrate reduction efficiency may continue to improve. Although groundwater monitoring is not

as representative of direct crop impact, due to its wider zone of influence, monitoring wells placed near the edge of willow buffers saw a declining trend in nitrogen loading from the time willow was planted. Willows have a longer growing season (March-November) than corn (May-October), which is advantageous for nitrogen reduction. Willows can intercept leached nutrients from fertilizers prior to reaching the groundwater system, when fertilizer is applied during corn planting in the spring and after the fall harvest.

Soil Health

Willows maintained higher annual soil moisture, had year-round vegetation coverage, and potentially increased subsurface soil organic matter, which all contribute to improved soil health. Although willows are known for their high nutrient and water consumption, in this study, willows had a more conservative daily uptake rate of water and nutrients as compared to corn.

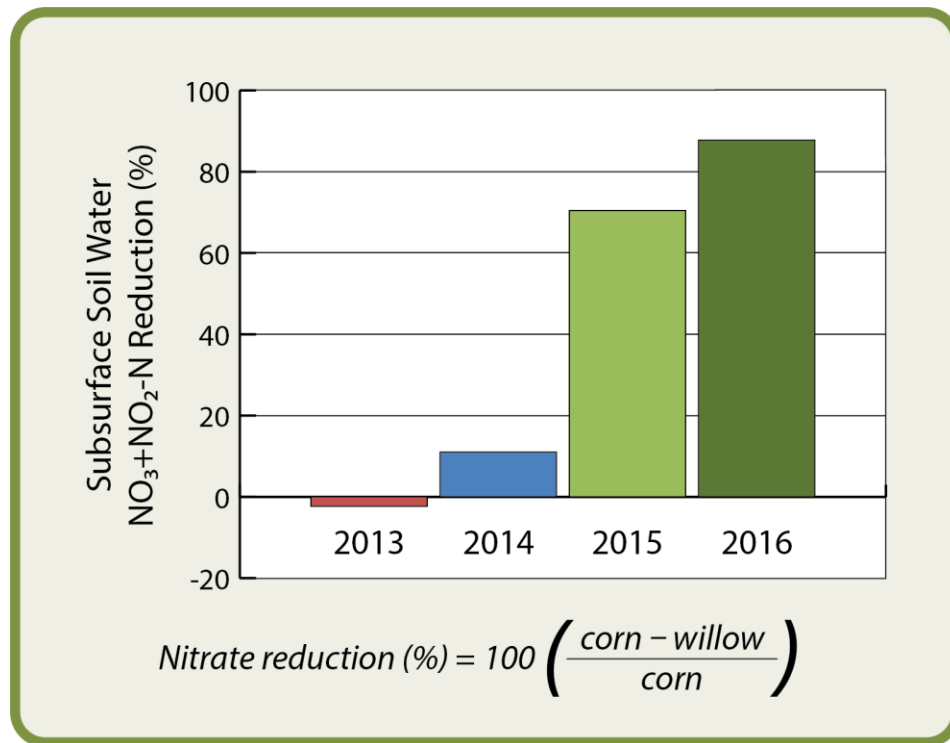


Figure 3. Nitrate percent reductions in soil-water by willow. “Corn” and “willow” in the nitrate reduction equation represent average soil water nitrate concentrations under each crop type. Positive reduction percentages indicate that the soil water nitrate concentrations were lower under willow than under corn.

Annual cumulative water use for willow was still higher than corn due to their longer growing season. However, willow plots still maintained higher soil moisture during the dormant months and did not have a significant impact on water-table level or water quantity during the growing months as compared to corn. This may be explained by willow's perennial growth pattern.

Soil nitrogen was found to fluctuate annually in willow plots, similar to corn plots, with no significant declines in nitrogen availability, in spite of the lack of fertilization. The only significant differences in soil nitrogen across the field potentially stemmed from soil type and slope. Willows, however, were found to have a possible impact on subsurface soil organic matter, which increased from 2011 (prior to willow planting) to 2015 and 2016 (after willow establishment). The difference in crop cover combined with the differences in land management practices between the two crops, with year-round vegetation coverage and no-till management for willow, may contribute to these observations. Further monitoring of this trend in organic matter will be required as the willows mature.

Greenhouse Gases

Nitrous oxide (N_2O) is a potent greenhouse gas, and soil emissions have been linked to fertilizer application as a result of soil microbial respiration usually under anaerobic (low oxygen) conditions such as after rain events (Ssegane et al. 2015). With no direct-fertilizer application and successful nitrogen reduction and recovery by willows, a large difference in N_2O emissions was seen between corn and willow plots (Figure 4). After willow establishment in 2013, soil N_2O emissions have been considerably reduced as compared to corn plots. However, soil carbon dioxide (CO_2) emissions seemed to fluctuate more widely each year, possibly as a reflection of yearly changes in climatic conditions.

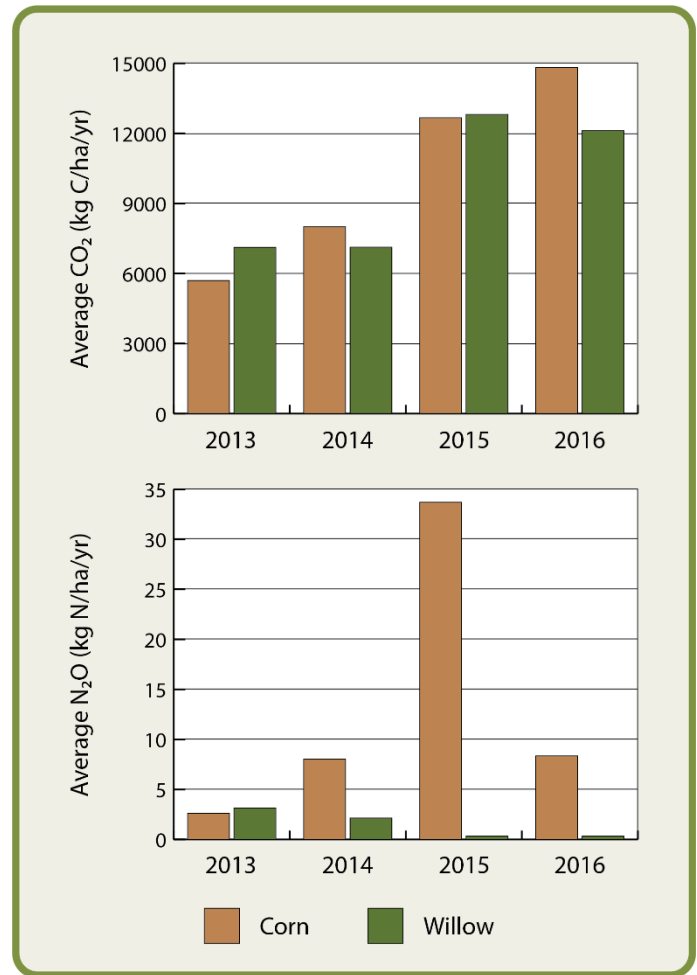


Figure 4. Average annual soil nitrous oxide and carbon dioxide emissions under corn and willow crop.

ECONOMICS OF MIDWEST WILLOW PRODUCTION

EcoWillow Modeling

The economic modeling of willow production using EcoWillow 2.0 ([Economic Analysis of Shrub Willow Biomass Crops](#)) (SUNY ESF 2015) solely for bioenergy did not yield a profitable production scenario (Ssegane et al. 2016). This was found regardless of three different willow production scenarios (Figure 5): (1) a large, single, dedicated field to maximize biomass production (business as usual); (2) a large buffer that incorporates ecosystem service provisions in a single subfield alongside a grain crop (single subfield buffer); or (3) smaller buffers in multiple subfields alongside grain crops across the watershed (multiple subfield buffers).

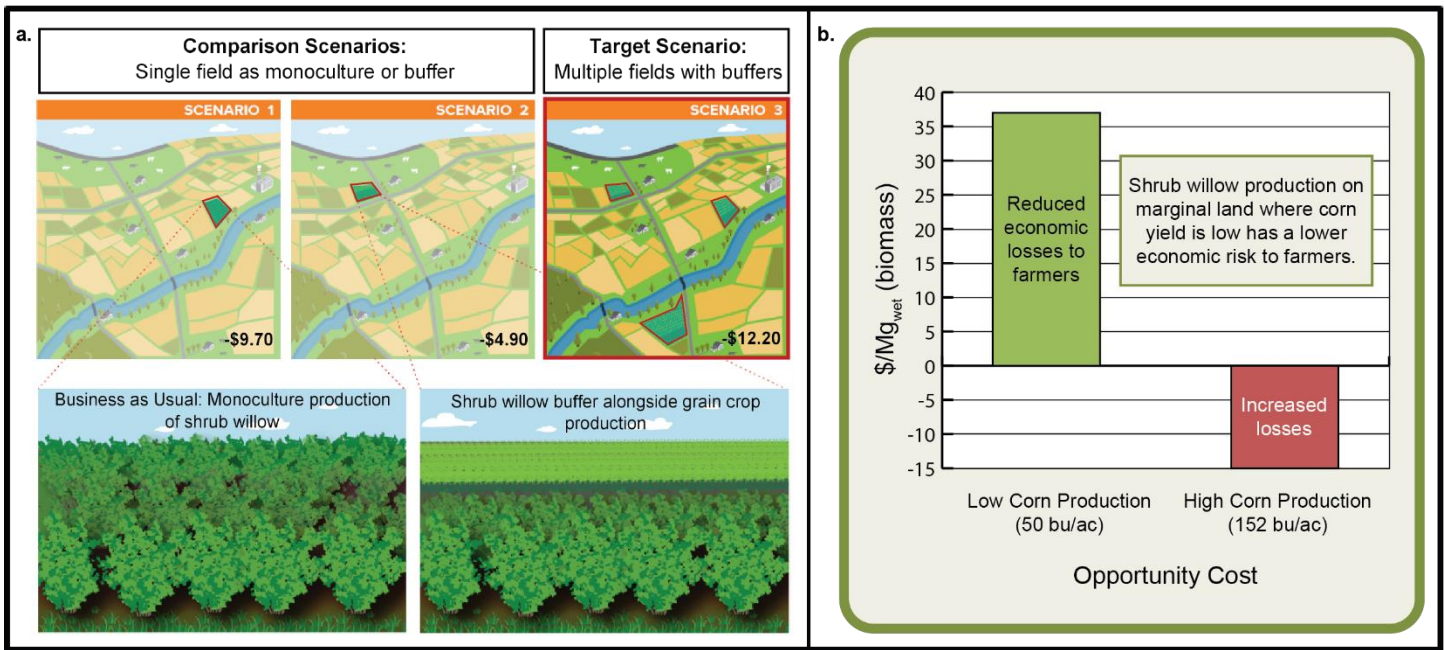


Figure 5. (a) EcoWillow willow production scenarios for the Indian Creek Watershed with their corresponding average annual net revenue (willow production costs + biomass revenue return) per wet metric ton of biomass produced (regardless of transportation distance or production scale), and (b) the opportunity cost of growing willow over corn on marginal land under varying corn yield potentials. The graphic for willow production scenarios was designed by Argonne National Laboratory.

Even with a strong market for willow biomass, there are tradeoffs between growing willow as a dedicated crop for biomass production (single crop, single field) versus growing it as a buffer alongside a grain crop, at one or more fields.

When planted as a buffer, there are significant cost-savings for farmers, as they do not have to allot space for headlands or directly fertilize the willows. However, the distance between the multiple field buffers would likely accrue an added transportation cost. Willow grown in a buffer saves costs by requiring less headland space and fertilizer use; which is equivalent to an additional 3.7–13 miles of travel distance for production and harvesting costs, based on production scale. By forgoing direct fertilizer costs and increasing production acreage by reducing headland space under a bioenergy buffer landscape design, the extra travel distance can be compensated for without increasing overall production costs. In addition, economic analyses suggest that the opportunity cost of growing willows over corn on marginal land may reduce financial losses and be more profitable for farmers on land where they are already losing money under corn production. On average, farmers’ losses were reduced by \$40 per metric ton (\$36 per U.S. ton) of

harvestable biomass, depending on the production scenario. If the value of various ecosystem services are included in the economics equation, then utilizing a landscape design, including willows as buffers, may substantially improve profits. Work is being conducted to deduce the economic value of ecosystem services that willows provide, based on current research (Ssegane et al. 2016).

Scaling Up: Field to Landscape to Region

In the interest of producing sustainable energy, site selection becomes very important to prevent both direct and indirect land use change from crop production to energy production. One criteria targeted by the U.S. “Billion-Ton” study was the use of marginal land for biomass production instead of prime crop land (U.S. DOE 2016). Marginal lands can be categorized as having either low crop productivity, being susceptible to nitrate or pesticide leaching, having high runoff and soil erosion, flooding, water ponding, or having other characteristics that producers deem to be either economically or environmentally marginal. However, selection of the production locations and the type of perennial bioenergy crop will be also be

dependent upon the environmental benefits from bioenergy crop production and ease of production.

For example, for areas at high risk for nitrate leaching, willow production may be a potential solution if the fields are untilled (as in our case or, potentially saturated buffer designs could be used for tilled-fields with research still in the beginning phase).

Site characterization (degree of slope and direction, water table depth, groundwater flow direction, soil characteristics including hydraulic conductivity and infiltration rate, among others) is done prior to planting to target the best locations for willow production to be the most effective at nutrient reduction.

However, producer access to production equipment, actual crop production potential on different soil types and different environmental conditions, field proximity to grain elevators or biomass depots, and biomass price also may play important roles in bioenergy crop selection (including cultivar/variety selection) and adoption of production at a larger scale. Many different production approaches/designs, and use of many different perennial bioenergy crops, may be important in scaling up bioenergy production from field to landscape to region.

CONCLUSIONS

Economic modeling suggests the high land prices in central Illinois, as well as the surrounding midwestern states, result in willow production for biomass alone to be unprofitable. However, by targeting marginal, underproductive lands for willow production, where farmers typically lose money when planted with corn, the opportunity cost for growing willows over corn reduces farmers' losses. In addition, the positive environmental benefits from producing bioenergy crops in strategic landscape patterns, such as buffer integration among grain crops, can be an added value. Current work is ongoing to define value to ecosystem services like water quality improvement, carbon sequestration, and habitat provision for potential pollinators and

pest control species, that will give an added economic incentive for bioenergy crop production.

For More Information

[Environmental Science \(EVS\) Division, Argonne National Laboratory](#)

[Meet the Plant that is Bridging Renewable Energy, Rural Development, and Environmental Benefits](#)

[Scientists study ways to integrate biofuels and food crops on farms](#)

[Changing the Bioenergy Equation with Willow Buffers in the Agricultural Midwest](#)

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