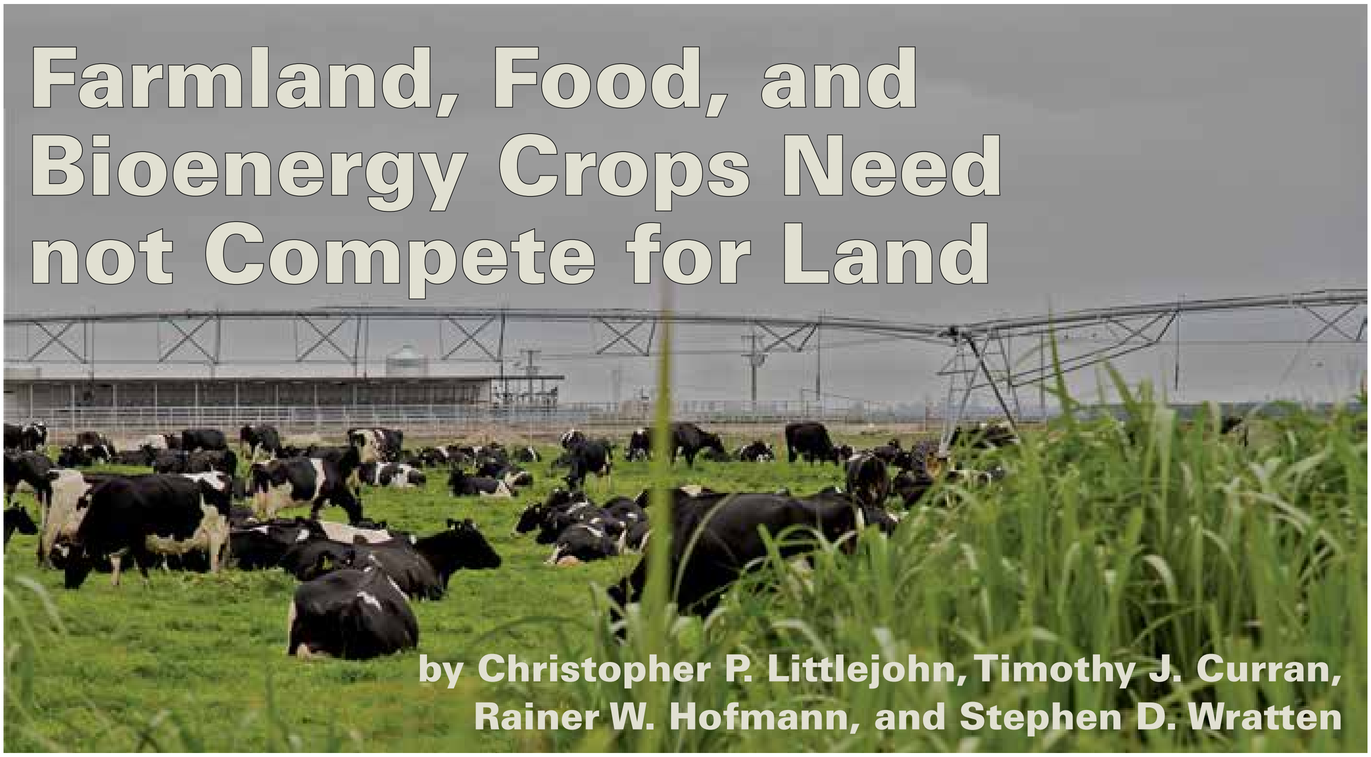
Farmland, Food, and Bioenergy Crops Need not Compete for Land

by Christopher P. Littlejohn, Timothy J. Curran, Rainer W. Hofmann, and Stephen D. Wratten



Steve Attwood, Auldwood

Mxg bioenergy shelterbelt growing on an irrigated intensive dairy farm on the Canterbury Plains in New Zealand.

In Brief

The need to mitigate the effects of climate change has resulted in some governments setting mandates to attain targets for bioenergy production. Recently, there has been concern that the large-scale use of first-generation biofuel feedstocks may result in 'food displacement.' New second-generation bioenergy crops can be produced on poor soil and provide a potential solution to this problem if grown on marginal land that was previously uneconomic for agricultural production. However, consequences of this production method are biodiversity loss and carbon release if previously fallow land is cultivated. Marginal land is also less agriculturally productive, and if profits from biomass plantations exceed those from food production, farmers will grow bioenergy crops on prime agricultural land in order to maximize profit.

Alternative approaches include utilizing mixtures of native grassland perennials grown on agriculturally degraded lands for bioenergy production and producing biodiesel from microalgae. In New Zealand, research is being conducted on the benefits of integrating bioenergy crops within the present farming system. In this research, the ecosystem services (ES) value of re-instated shelter on irrigated dairy farms is assessed using the novel approach of adopting a bioenergy crop for shelterbelt creation. Together with on-farm ES as well as those external to the farm, ES delivery from shelterbelts—rows of trees or shrubs planted to provide wind protection—potentially improves the profitability of the farming enterprise. By planting a shelterbelt of *Miscanthus* x *giganteus* (Mxg), a sterile hybrid bioenergy grass that grows four meters tall, in the northerly corners of fields, we were able to measure the multiple ES advantages generated including shelter for livestock, the growing of a harvestable crop for fodder or renewable fuels, and benefits from creating a new on-farm habitat such as a refuge for beneficial predatory insects and pollinators. Findings show that pastures benefiting from the shelter of the grass have reduced evapotranspiration rates, the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants, resulting in increased yields. In the sheltered field areas, there was a positive influence on soil mineralization rates and beneficial insects. By having bioenergy crops as a valuable co-product of the existing farming system, in this case dairy production, the problem of replacing land used for food production with bioenergy cropping is overcome. The loss of food-productive land is potentially more than compensated for by the value of ES benefits gained if long term sustainability of the farming system and global threats associated with fossil-carbon use are considered.

As the source of two-thirds of global GHG emissions, the energy sector will be pivotal in determining whether or not climate change goals are achieved. The International Energy Agency predicts that world energy demand will increase by one-third by 2035. If government policies promote the use of low-carbon energy sources—which includes biofuels—to 40 percent of total world energy use by 2030, then energy-related carbon dioxide emissions will still rise by 20 percent. This leaves the world on track for a long-term average temperature increase of 3.6°C.[1] The need to reduce the dependence on fossil fuels to meet emissions targets outlined in climate change mandates and to improve energy security has already resulted in billions of dollars being spent worldwide to support the biofuel industry.[2] For example, the European Commission in 2008, as part of its 'climate change package,' adopted the Directive for Renewable Energy (DRE), which legislated the use of biofuels in the transportation sector.[3] The Directive insisted that "the share of energy from renewable sources in the transport sector must amount to at least 10 percent of final energy consumption in the sector by 2020."[4] In 2012, global subsidies for production of renewable energy to aid achievement of mandated production targets reached US $101 billion, being highest in the European Union (US $57 billion) and the United States (US $21 billion).[1]

The 2008 world food crisis, where prices for basic staples increased by 83 percent,[5] resulted in an examination of bioenergy policy. As articulated by Josette Sheeran, Executive Director of the UN World Food Programme, blame was directed at the increased food demand from developing countries—notably China and India—but this was a convenient oversimplification of the causes. "It takes the scrutiny off structural causes of the crisis, such as the trade liberalization policies advocated by the International Financial Institutions (IFIs) that have wreaked destruction on the agricultural base of the developing countries and destroyed their ability to feed themselves," Sheeran noted during the crisis.[5] Nevertheless, the rise of the middle class globally is driving more meat consumption, which requires high rates of crop calorie production to sustain it, putting further pressure on agricultural land to meet ever-increasing demand. This in turn further informs the food versus fuel debate.

Key Concepts

- **Land-use change is a potential environmental risk that may be exacerbated by bioenergy development.**
- **Many are concerned that the potential competition between energy crops and food crops might result in increased food commodity prices.**
- **An alternative approach is to integrate second-generation bioenergy crops into the farming system by using them to recreate shelterbelts. Recent changes in farming practices, such as the installation of center-pivot irrigation with a height clearance of greater than two meters, have led to widespread removal of shelterbelts. Mxg can compensate for these changes as it allows the center pivot to pass through it and is not restricted by the height of the pivot.**
- **Biomass production is only one of 15 possible ecosystem services shelterbelts can provide that improve sustainability of the farming system.**
- **Renewable diesel plants using US technology can generate this fuel from biomass. If farmers are able to develop a small generating unit, the use of this technology would allow for on-farm production and energy consumption, further creating a sustainable production system.**

Growing bioenergy crops has considerable benefits, the principal ones being GHG sequestration and the development of energy independence as these crops can reduce consumption of fossil fuels. Bioenergy crops absorb carbon from the atmosphere via the photosynthetic process, compensating in this way for the carbon dioxide (CO_2) released on combustion. In contrast, carbon in fossil fuels has been sequestered underground for millions of years, and their burning add to the present atmospheric concentrations of GHG. Despite these benefits, changes in land-use patterns, with future increasing areas of energy crops being produced instead of food, is potentially detrimental and an important consideration internationally.[6]

Even though the US leads the world in total biofuel production (Table 1), biomass fuels only provided about five percent of the energy used in the US in 2013. Of this five percent, about 45 percent was from wood and wood-derived biomass, 44 percent was from biofuels (mainly ethanol), and about 11 percent was from municipal waste. Ethanol is produced mainly from corn, which is a high-input, annual monoculture and an example of a first-generation bioenergy crop. These are existing food crops that can be used to produce biofuel, either ethanol or biodiesel, using either carbohydrate from grain crops or sugar cane stems or oil from oilseed rape (canola), palm oil, and soybean. Bioethanol is the most widely produced biofuel globally with worldwide production being 1,322 billion liters in 2010 compared to only 15 billion liters of biodiesel. Bioethanol is easy to produce but has an energy density one-third of that of diesel and is mostly used as a transport fuel by blending with petrol. Typical blends use 10 percent ethanol, but with engine modification, 85 percent ethanol can be used. Biodiesel is similar to mineral diesel and has a similar combustible energy content. The low interest in the production of biodiesel

Region	Biofuel Production (billion litres)	Major Feedstock
Europe	10	Corn / soya bean / OSR
North America	40	Corn / soya bean
South America	25	Corn / sugar cane
Africa	2	Animal dung / jatropha
Australia/Asia	4	Palm oil / OSR

OSR – oil seed rape (Canola)

Authors

Table 1. World biofuel production is largely based on first-generation bioenergy feedstocks

in the US—three billion liters in 2010 compared to 72 billion liters of bioethanol—is due to the strict emissions standards the fuel has to meet, meaning it has to be blended with mineral diesel before being used as a transport fuel. This is not an issue with renewable diesel, which can be produced from lignified material including second-generation bioenergy crops and used as a 'drop-in-fuel.'

The ratio of the energy produced from combustion compared to that used to grow, harvest, and transport the crop gives a measure of the net energy gained, with a value higher than 1 indicating a positive energy balance. The energy ratios of first-generation biofuels are highly variable. Stromberg and Asparatos gave the following net energy ratios: wheat bioethanol (1.6 to 5.8); palm oil biodiesel (2.4 to 2.6); and jatropha seeds used for biodiesel production particularly in semi-arid and remote areas of developing countries (1.4 to 4.7).[7] Corn bioethanol (0.8 to 1.7) and certain soybean biodiesel practices (1.0 to 3.2) demonstrated lower ratios, below 1.0 in some cases. Sugarcane was the only crop with relatively high ratios (3.1 to 9.3), which makes it reasonably 'sustainable' as it also has high GHG reduction potential.[8] In Brazil, there are 9 million vehicles that use sugarcane ethanol or ethanol blends, and to date, this high usage has not had any effect on food supply. Also, a major drawback of sugarcane is, depending on location, its soil erosion rates are 5.2 times greater than soil formation rates.[9] Land degradation is a major concern with the expansion of first-generation biofuel crops. The expansion of corn and cassava into already-degraded upland agricultural systems in Southeast Asia can increase the risk of soil runoff and sediment generation.[8]

These concerns have led to an increased interest in the use of second-generation bioenergy crops and perennial energy crops, which include a variety of native and non-native grasses and woody plants grown purely for energy production. These require fewer inputs, have superior energy ratios, reduce GHG more than annual cropping, and enhance water quality and habitat quality for beneficial insects and other wildlife.[12] The lignocellulose in perennial forage crops is a more energy-dense material than the starch and sugars used from first-generation bioenergy crops. It represents a potentially vast and renewable source of biomass feedstock, and recent advances in technology enable production of biodiesel and renewable diesel from lignocellulose.[13] Renewable diesel is chemically the same as mineral diesel and can serve as a direct replacement. Biodiesel is not and tends to be blended before it can be used if engine modifications have not been made. Both are derived from plant material but have different methods of manufacture. The higher yields of second-generation bioenergy crops means the same amount of biofuel can be produced from a smaller area of land. This is important when considering the Life Cycle Analysis (LCA) of biofuels. Energy ratios and GHG emissions are the principal components used to generate LCAs, which are then used to investigate the environmental impact of biofuel production. Monitoring the application of minimum targets on GHG emissions reduction to biofuels as well as estimating their substitution efficiency to fossil fuels is subject to significant uncertainty and inaccuracy due to the associated methodology. The introduction of biofuels in the US

Ethanol Production (billion litres)

Country	Major Feedstock
United States	40 Corn / Wheat
Brazil	25 Sugar Cane
China	3 Corn / Cassava / Rice
Canada	2 Corn / Wheat

Major Producers of Bio-ethanol 2010 (billion litres)

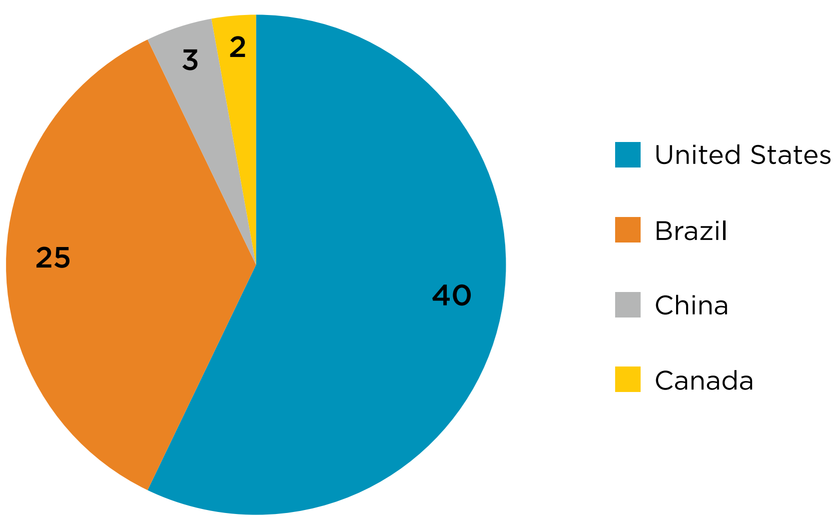


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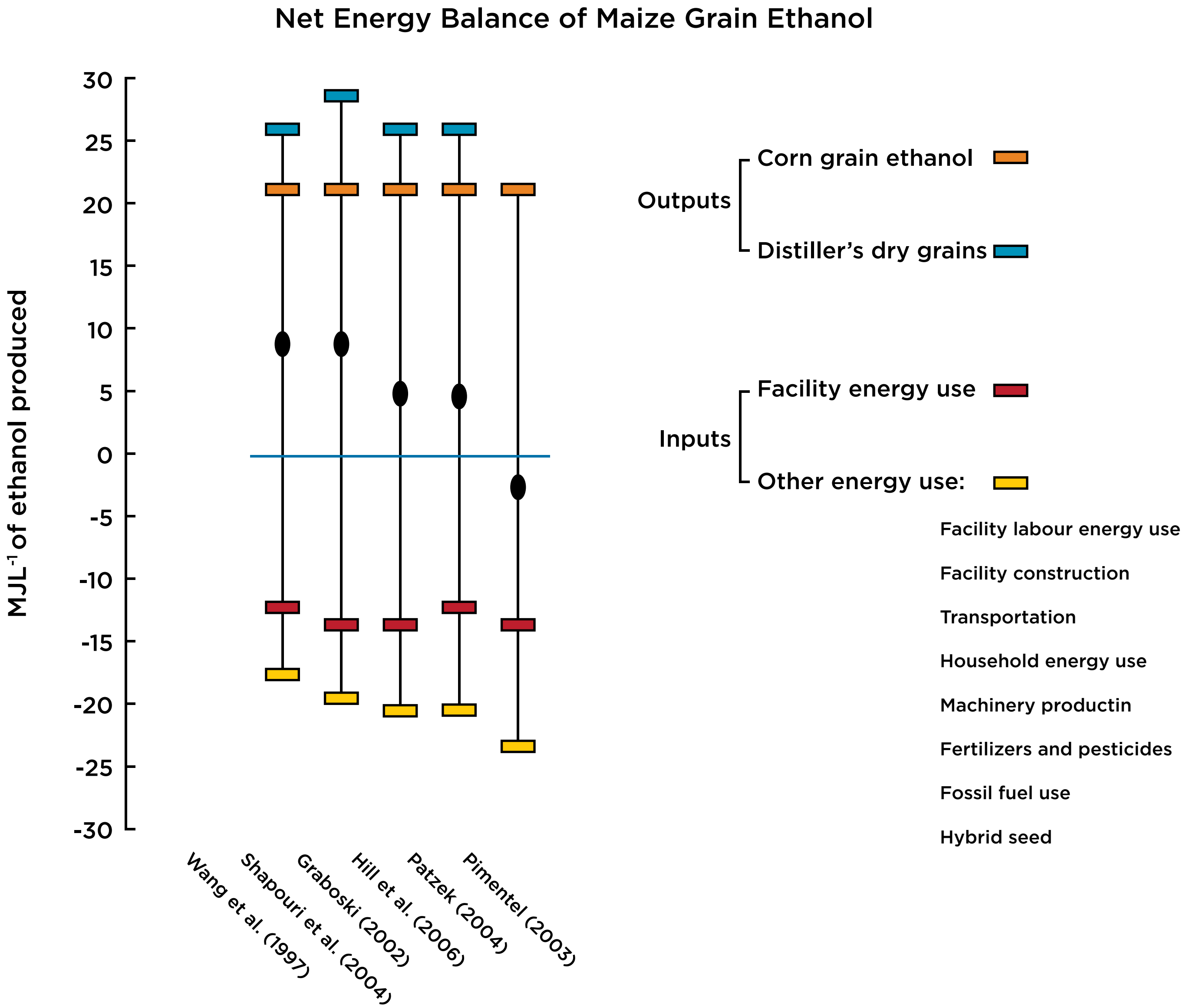
Table 2. World bio-ethanol production in 2010.

has expanded total corn acreage but diverted it away from food and feed. The expanded corn acreage may take land away from lower value crops, which may move into marginal land that is not currently farmed. In Brazil, grazing activity displaced in the Cerrado region by sugarcane expansion may encroach into the Amazon forests, although sugarcane may not be directly cultivated in that region. Thus, when one considers the overall effect of producing biofuels on a large scale on net GHG emissions, the indirect land-use effect has to be taken into account.[14]

The wider adoption of second-generation bioenergy crops would create the opportunity of using marginal, rather than prime, cropland for crop production. This is due to the ability of marginal lands to produce high yields without requiring high nutrient inputs because they are harvested when they have senesced. Therefore, a common response to the potential competition between energy crops and food crops is to suggest that marginal, rather than prime, cropland be targeted for bioenergy production. There are two major drawbacks of this. First, production still needs to be economically viable and yields are still likely to be lower when crops are grown on marginal lands as they tend to have reduced water availability. Second, marginal land, if not being used for agricultural production, is likely to have a high biodiversity and ES value. Of the six main direct causes of biodiversity loss identified in the Millennium Ecosystem Assessment, four are directly associated with biofuel expansion.[15] Moving bioenergy production to marginal land is often associated with the conversion of natural ecosystems such as grassland and forests, resulting in greater biodiversity loss than when compared to the conversion of cultivated land.[16] Marginal lands also deliver a number of ES benefits that humans derive from ecological processes that contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet.[17] These systems, such as regulatory systems including water, climate, pest regulation, and pollination, are critical to the functioning of the earth's life-support system.

Agricultural landscapes potentially provide humans with a variety of valuable ES. They provide food, fiber, and animal feed. They regulate the quality of our water, sequester GHGs, host beneficial insects and other wildlife, and provide us with a variety of recreational opportunities. Despite the importance of these multiple services, agricultural landscapes tend to be designed to maximize only provisioning services such as crop production as these generate goods that can be sold, therefore yielding income for producers and landowners. For agricultural landscapes to be sustainable, they need to balance provisioning services that primarily accrue to individuals with regulating cultural and supporting services that benefit communities more broadly.[18]

A prime example of the conflict between the aim of using agricultural land to produce products and the

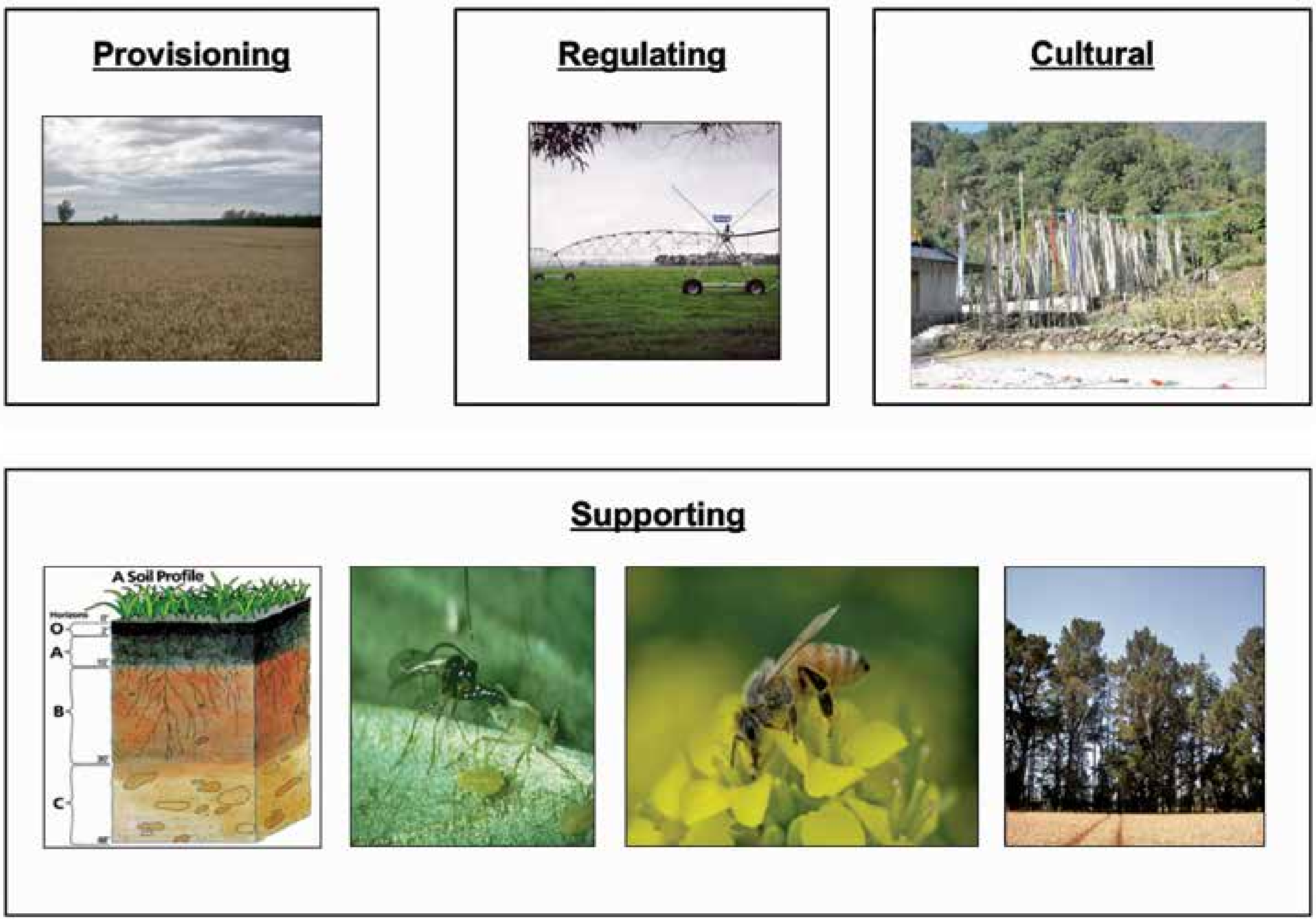


Adapted by authors from Hill et al.

The net energy balance of maize grain (corn) ethanol as estimated by six recent studies, most recently by Hill et al.[10] All eleven input and output categories are ordered as they are shown in the legend, but some are so small as to be imperceptible. Only the estimate of Hill et al.[10] includes all eleven categories. The estimated net energy balance (the sum of the outputs minus the sum of the inputs) from each study is shown by the placement of a black dot.[11]

need to generate sustainability by maximizing ES delivery is the chequered history of shelterbelt use in agricultural systems. Shelterbelts have an important role in improving the sustainability of the farming system, but they are undervalued and consequently have been declining. Their removal is either through progressive deterioration, a lack of funding or incentive to replace them, or from active removal due to changes in farming practices such as the installation of center-pivot irrigation systems. For example, in 'The Great Plains Forest Shelterbelt Project' in the US, the planting of single-row tree shelterbelts over a 167-km wide belt extending from Texas to the Dakotas, was instigated by President Roosevelt in 1934 to mitigate harsh environmental conditions, improve crop yields, and preserve soil moisture.[20] This led to the planting of 96,356 ha of trees, or 30,895 km of shelterbelts. Despite the advantages shelterbelts provide to the surrounding area, this massive effort to establish and maintain shelterbelts has never been repeated, and their numbers have been continually declining. Marotz and Sorenson's research 'Depletion of a Great Plains Resource: The Case of Shelterbelts' found that part of the reason for the decline was a lack of incentive to maintain and replace aging trees combined with the increase in popularity of center-pivot irrigation.[20]

The consequences of shelterbelt



Adapted by authors from Wratten et al., Ecosystem Services in Agricultural and Urban Landscapes, 2013

Various ecosystem services provided to farming systems by shelterbelts.

removal is of great concern to the local community. Trees around farmsteads can reduce energy bills by blunting the cooling force of the winter wind or providing shade from the summer sun. Trees in pasture areas provide the same benefits to livestock. Tree rows can provide living snow fences if they are planted in strategic locations and in recent years, trees have also been planted along creeks or streams to help filter water. Trees can also provide an important refuge for wildlife.

In the February 4, 2013 edition of the Dakotafire, a media project that reports on issues of importance to rural communities in North and South Dakota, the lead article, entitled "Shelterbelts, One of the Great Soil Conservation Measures of the 1930s, Are Being Removed" debated the reasons for and consequences of shelterbelt removal. The farmers' short-term view was that there were many reasons to take out a shelterbelt or windbreak and not nearly as many to maintain them or plant new ones. In recent years, the most persuasive argument for removing tree rows is the little bit of land underneath that could be growing corn or soybeans. "It's hard to leave a tree belt [to] sit there, when land, like in Brown County, sells for $13,000 an acre," said one farmer quoted in the article. But the effect of shelterbelt removal on the long-term sustainability of the farming system is a primary concern.

"It does bother me when shelterbelts in our records, planted by the taxpayer, are cleared away, and those thousands of dollars that were spent are simply gone" said a district conservationist quoted in the article. "But I don't put the blame on the individual making a business decision. They're trying to make a buck, trying to make a living…I want them to make money—but I don't want them to make that money just for one or two harvests, but for as long as they are in business" he said.

In the Canterbury region of New Zealand, a similar grant-assisted shelterbelt planting project was started in the 1940s to protect productive agricultural land from the drying northerly winds common to the area. Shelterbelt removal in the region has been done through the conversion of large parts of the area to dairying, which relies on center-pivot irrigation to be profitable. The pivot circumnavigates the milking platform (the grazed area used for milk production), often at a height as low as 1.5 meters. Consequently, all plant-boundary shelter is removed leading to large expanses of open pasture. The effect is that extensive areas of the Canterbury plains now comprise of large expanses of a flat, treeless landscape of low diversity pasture. The resulting production system is low in ES provision, the most visual of which is low aesthetic value, which creates a public perception of unsustainable dairying.[21]

An alternative approach to address the concerns of replacing food with fuel, that is, production of bioenergy crops and the loss of shelterbelts and their associated benefits, is to integrate the bioenergy crop into the present farming system as shelterbelts. This is not the sole solution available for addressing the food versus fuel dilemma. Others include utilizing mixtures of native grassland perennials grown on agriculturally degraded lands for bioenergy production and producing biodiesel from microalgae. Tilman et al. showed biofuels produced from low-input, high-diversity (LIHD) mixtures of native grassland perennials can provide more usable energy, greater GHG reductions, and less agrichemical pollution per hectare than can corn grain ethanol or soybean biodiesel.[22] However, their claim that LIHD biofuels can be produced on agriculturally degraded lands and thus need neither displace food production nor cause loss of biodiversity via habitat destruction is debatable as these lands are displaced from their fundamental role of producing meat and milk foods via grazing animals.[23]

An equally acceptable alternative is to consider the potential role of human-inedible cereal crop residues in providing bioenergy. Producing biofuel from microalgae is the only renewable bioenergy that has the potential to completely displace liquid transport fuels derived from petroleum. However, at present, the economics of production are not favorable enough to establish competitiveness with petroleum-derived fuels.[23]

Using bioenergy crops as shelterbelts not only can help avoid food production displacement, it can also enhance ES delivery from the farming system, improving its sustainability and reducing its external costs, including costs incurred through damage to the environment such as the contamination of waterways or the degradation of soils. Improved food yield due to shelter-enhanced production has the potential to partly or wholly offset these costs.

Shelterbelts have an important role in improving the sustainability of the farming system, but they are undervalued and consequently have been declining.

Porter et al. developed a new production system based on a combined food, energy, and ecosystem services (CFEES) approach.[24] In this research, the planting of the CFEES system was established to create an agroecosystem that was a net-energy producer and developed more energy in the form of renewable biomass than was consumed in the planting, growing, and harvesting of the food and fodder. The bioenergy component was represented by belts of fast-growing trees (willows, alder, and hazel) that are planted orthogonally to fields that contain cereal and pasture crops. The benefits from the shelterbelts were evaluated by assessing the value of the ES delivered by them. Resultant increases in the delivery of ES improved the sustainability of the farming system and at the same time the shelterbelts produced their own primary production output in the form of wood for energy production.

An alternative to woody shelterbelts, the use of perennial tall grasses as second-generation bioenergy crops creates a novel means of recreating shelterbelts. The Southeast Asian tall grass Mxg is widely used in Europe and the US where it is planted in whole fields as a bioenergy crop. Mxg is a perennial that senesces each year, regrows in the spring, and is harvested just before spring regrowth. It has a high yield output, low inputs due to being harvested after senescence when the majority of plant nutrients have been translocated to the rhizome, a high energy ratio of greater than 20:1, and rapid growth. Its mature height is four meters year on year once into its third season, and it has multiple end uses, including production of renewable diesel. Unlike woody shrubs and trees, this grass allows the center pivot to push through it and so is not restricted in height. Mxg does not do well in heavy soils and requires annual rainfall amounts of greater than 600 mm.

Mxg is one of the best performing bioenergy crops. Recent analyses conclude that in the (warm) temperate zone, Mxg is the bioenergy crop that seems able to deliver the highest net GHG mitigation and has the highest yield in terms of energy per hectare when compared with bioethanol, biodiesel, and short rotation coppice willow biomass.[25,26] The combination of an annual harvest and a good energy yield per hectare (substantially more than that for wood species) gives the plant considerable potential as a bioenergy crop.[27] Mxg yields are maximized under irrigation, so shelterbelt creation on irrigated farms means the

Keri Sailer/LaMoure Chronicle/via Dakotafire Media

Trees removed from a windbreak in LaMoure County, US, are piled up to dry so that they may be burned later. Aging shelterbelts and windbreaks are being removed all over the eastern Dakotas.

production benefits associated with a regular and sufficient water supply are harnessed through the existing farming infrastructure.

Mxg also has many attributes that make it favorable for creating shelterbelts. It is a naturally occurring, sterile, and noninvasive hybrid between *Miscanthus sinensis* (Andersson) and *Miscanthus sacchariflorus* (Maxim) Franch,[25,26,28] and originates from Asia. It has no known vulnerability to pests and diseases outside of its native areas, and weed control is needed only in its first two seasons of growth, making it a low-maintenance, easily managed shelterbelt plant. Once planted, it can remain productive for at least 20 years, and being sterile with a slow rhizome spread, there is minimal risk of it spreading to unwanted areas.

At Lincoln University in New Zealand, research is being done on the suitability of using Mxg for creating shelterbelts and results to date indicate it is very effective. Presently, shelterbelts consisting of six rows of Mxg were planted on an intensive center-pivot irrigated dairy farm on the Canterbury Plains in New Zealand. The shelterbelts were planted in the northwest corner of six fields in an L-shape 80 meters long and seven meters wide. The primary aim was to provide shelter that would not impede the progress of the center pivot and would allow protection from the drying northerly winds that are a predominant feature of the Canterbury Plains.

Now halfway through its third season, the shelter structure is over three meters tall, is robust, performs well in very severe gales, bending rather than breaking in the wind, and has the desired porosity to allow the shelter effect to extend far into the field. A general rule is that the distance of shelter effect into the field is 10 to 12 times the height of the shelter.[29] Shelter effect would be expected to increase as the Mxg plants mature.

It can be argued that using a non-native plant in this way will not enhance the biodiversity of existing

Newly established Mxg bioenergy shelterbelt two months after planting on a New Zealand dairy farm.

barren monoculture landscapes. However, most shelterbelts are often comprised of non-native plant species. Mxg has many features, such as reduced winter cover, that allows other plants to grow within its shelter and thus creates a diverse habitat. ES delivery from the shelter are Mxg biomass yield; pasture yield; pasture evapotranspiration (ETz) rates, where liquid water is removed from an area with vegetation and into the atmosphere by the processes of both transpiration and evaporation; organic matter mineralization rate; earthworm abundance; and occupancy of the shelterbelt by endemic New Zealand lizards (skinks), bumblebees, and rodents. A study of insect diversity within the shelterbelt is ongoing, but initial results showed an increase in beneficial predatory arthropods within the shelter compared to the open paddock.

Current Mxg growth analysis suggests annual yields of 3- to 10-year-old Mxg plantations grown under irrigation in Canterbury would be close to 30 tons per hectare per year ($t\ ha^{-1}\ yr^{-1}$). If this is used to produce renewable diesel, 9,000 liters of this fuel per hectare would be produced. At a replacement cost of US$0.89, this equates to a gross margin of US$8053 $ha^{-1}\ yr^{-1}$.

Pasture dry matter yield was calculated from pasture height readings collected from a C-Dax pasture meter.[30] This meter measures grass cover and can take numerous pasture cover readings (200 per second) across a field that can be used to produce yield maps. Further analysis of the data was used to calculate pasture yield from shelter effect.

Christopher Littlejohn

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A center-pivot irrigation system in New Zealand.

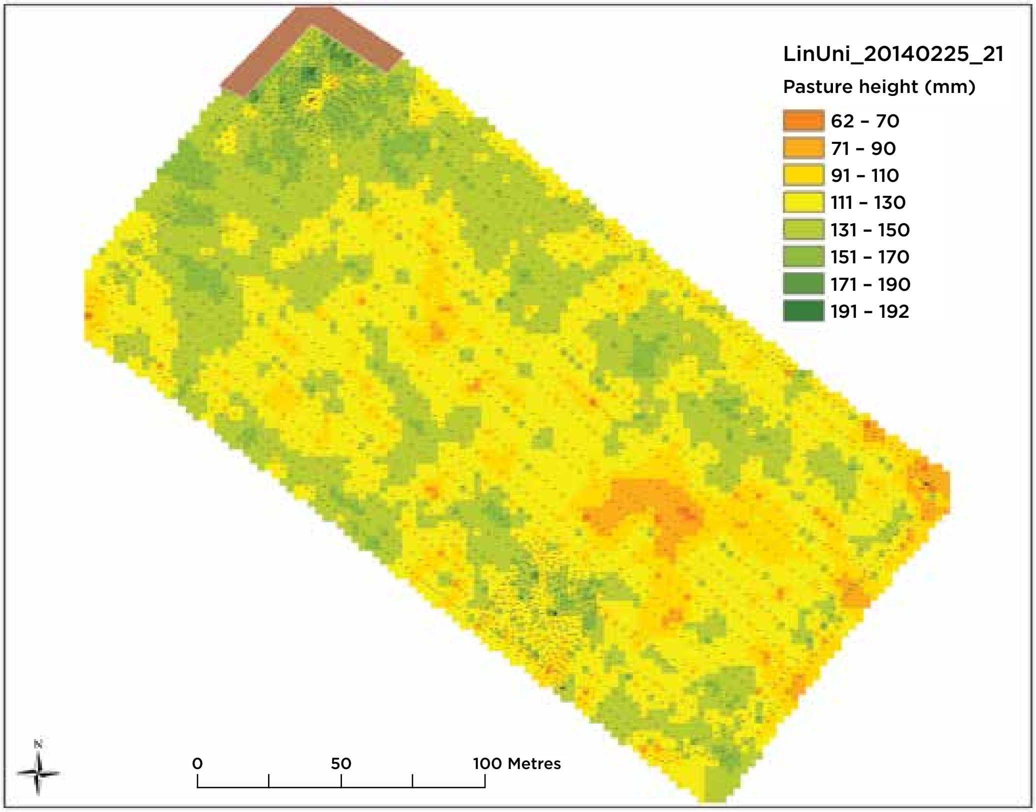
Readings taken within the shelter area—the 40 by 40 square meter section of field enclosed on two of its northern sides by the shelterbelt and an equivalent-size control area of open field—showed pasture yield increased by 18 percent when the pasture was sheltered from drying northerly winds.[31]

ETz rates measured using data loggers with environmental sensors over one month in midsummer in three separate fields showed a reduction in ETz of 25 percent in sheltered areas (unpublished data). Hand-held porometer readings, used to measure leaf stomatal openings (stomata are closed when plants are water-stressed, reducing photosynthesis rates and growth), showed that plants in sheltered areas keep their stomata open for longer.[31]

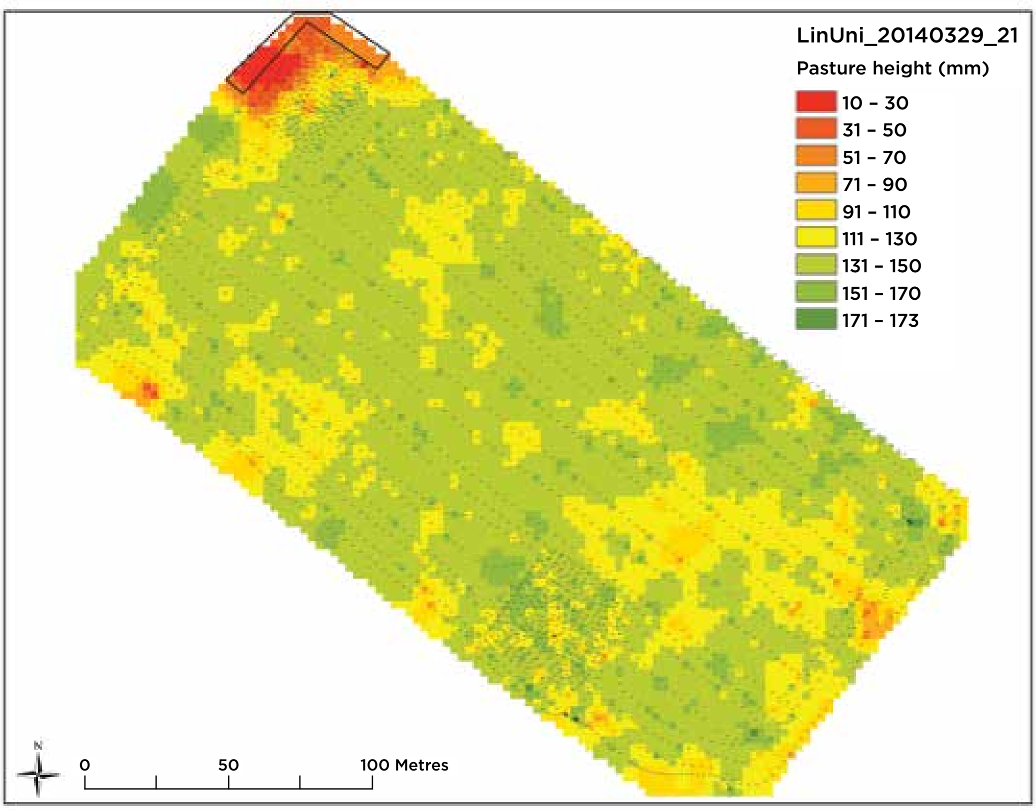
Organic matter mineralization rates measured using lamina probes showed that the mean mineralization rate at the distance of maximum shelter effect (six meters) in year two of this study was 13 percent higher than in the open field.[32] Using soil quality data, it can be calculated that this increase would release 495 kg of nitrogen ha^{-1} yr^{-1}. This equates to a value of US $242.55 per hectare (unpublished data). The increase in mineralization rate was recorded up to 12 meters from the shelter in Season Two when Mxg was 2.5 meters high.

In Season Three of the trial, the rate of decline in earthworm weight at increasing distances out from the shelter was significantly different at the 95 percent level. For control areas, this was not the case. At a distance of 40 meters from the shelter, there was a decrease of 2.5 g in earthworm weight per spade sample (0.008 m^3 of soil) (unpublished data). Overall, there were three times as many earthworms in the shelter areas compared to the control, open field area. Earthworms are the most important component of the soil biota in terms of soil formation and maintenance of soil structure and fertility. They bring between 10 and 500 t ha^{-1} yr^{-1} of soil to the surface, and it was estimated that soil biota aids the formation of approximately 1 t ha^{-1} yr^{-1} of topsoil.[33]

Rats and hedgehogs didn't seem to favor Mxg shelterbelts, but the shelters were the preferred habitat of skinks and mice. Skinks and mice are both near the top of the food web in the New Zealand agriculture setting, so their relatively high numbers indicate high biodiversity and abundance at the lower trophic levels.[34] Both feed on invertebrates, which can provide many ecosystem services to humans including pollination, biocontrol of pests, soil health, and ecosystem resilience and function.[35,36] Mice are pests in New Zealand, being responsible for the decimation of native invertebrate populations,[37] and indirectly affect native bird predation by providing



Map A.



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Map B. Pasture yield maps of one shelterbelt trial field from C-Dax records using the Kriging method of analysis in ArcMap 10.1, showing possible shelter effect in A (shelter present) but not in B (shelter absent). A – Mxg shelter 2.5 m high. B – Mxg shelter removed by previous grazing due to a southerly wind causing cows to crowd in this area, break the fence, and eat the shelter.

Christopher Littlejohn

Placement of bumblebee motels and skink rest areas into young Mxg shelterbelts.

food for their predators such as possums and stoats.[38] Their nests do provide suitable nesting sites for bumblebees,[39] which are valuable pollinators. However mice also prey upon bumblebees,[39] thus the mouse population supported by Mxg is potentially more of an ecosystem disservice than a service. The Mxg shelter itself acted as a refuge for nesting bumblebees. The only 'bumblebee motels'[40] placed around the farm to have active nests were those placed in the Mxg shelter.

On dairy farms where virtually all shelter has been removed to accommodate the center pivot, the welfare concerns for stock are an important consideration. Although the current work did not measure actual benefits to stock, cattle utilized the shelter even when it had reached only half its expected height to protect themselves from cold southerly winds.

Arguments against using field strips instead of whole-field plantings for bioenergy plantings are that the amount of biomass produced on a farm level would be low. Planting of an Mxg shelterbelt around each paddock on 100 ha uses approximately seven percent of the land area, or seven ha of land. At yields of 9,000 liters of renewable diesel per hectare, this would produce 63,000 liters of renewable diesel. Average diesel consumption in 2008 for each farm in New Zealand was 6,800 liters.[40]

As mentioned in the Dakotafire media report, the main argument by farmers against planting shelterbelts was the loss of productive agricultural land. This raises a number of issues, notably that farming practices are largely dictated by the pursuit of primary production irrespective of the external costs of the methods used to achieve these and that the resulting delivery of ES are not being valued.[27] It must be recognized that field-margin plantings deliver benefits that mitigate the external costs associated with intensive production methods such as reduced nitrate and phosphate run-off if the shelter is planted as a riparian strip, GHG emissions mitigation, carbon sequestration, enhanced biodiversity, and improved aesthetic farm appearance.

Previous research suggests that integrated farming systems have the potential to improve the energy and GHG balances and biodiversity compared to both organic and conventional systems.[41] For example, Brandel et al. estimated above-ground biomass carbon sequestration rates of 20-year-old, single-row shelterbelts at 30 to 60 percent of their final height were 9.14 tons per kilometer ($t\ km^{-1}$) of carbon for conifers, 5.41 $t\ km^{-1}$ for hardwoods, and 0.68 $t\ km^{-1}$ for shrubs.[42] For Mxg, it is estimated for crop yields of 20 $t\ ha^{-1}\ yr^{-1}$, that if grown on 10 percent of suitable land area in the European Union (EU), the total carbon mitigation could be about nine percent of the EU total carbon (C) emissions for the 1990 Kyoto Protocol baseline levels.[43] In the current research, seven meter wide Mxg shelterbelts around each field would constitute seven percent of the farmed area. The total net annual GHG emissions (CO_2 equivalent) for New Zealand in 2012 was 65 million tons of CO_2.[44] If planting seven percent of the cultivated area of New Zealand (11.2 million ha), the total potential soil organic C mitigation potential would be 255,000 tons of C per year ($t\ C\ yr^{-1}$) in addition to the 671,000 $t\ C\ yr^{-1}$ mitigated if coal was replaced by Mxg as a furnace fuel, such as that used in dry milk production. This is based on a total C mitigation value of 7.2 $t\ C\ ha^{-1}\ yr^{-1}$ for Mxg DM yields of 20 $t\ ha^{-1}\ yr^{-1}$.[43]

The drawback of using Mxg as a shelterbelt, particularly on livestock farms, is that it is palatable to stock and so needs fencing throughout its productive life. However, if the plant is eaten, no long-term damage is done as it behaves as any other grass, regrowing from the rhizome. The fact that it senesces in the winter means shelter is reduced to some extent from midwinter to late spring and full shelter height is not reached until midsummer. On irrigated dairy farms in New Zealand, this was ideal as shading of pasture in the spring delays growth and the aim was to create

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An Mxg bioenergy shelterbelt in its third season on a New Zealand dairy farm.

shelter from drying northerly winds that predominate in the summer. Mxg shelter does not need harvesting to remain productive. If not harvested, some shelter remains until regrowth is fully established, and if harvested, this operation does not occur until early spring at the start of regrowth. If needed in early spring, stock shelter could be provided by external shelterbelts not restricted in height by the center pivot. Once well established, which occurs midway through the second season, maintenance of the shelterbelt only involves harvesting.

Upscaling of the present study through the production of plantlets from tissue culture is an established process and can generate hundreds of thousands of plants within one season. Planting of rhizomes is an alternative method, but this is slower to upscale. Using plantlets, when compared to conventional arable crops, is more expensive. But when costs are considered over the productive period of 15 to 20 years, then average annual gross margins are only 20 percent less than barley. New technology developed by New Energy Farms, which was used to establish Mxg crops for the University of Iowa Biomass project,[45] produces rhizome pieces at a cost of US $0.08 per unit compared to plantlet costs in New Zealand of $0.50 per unit. However, specialist machinery is needed to plant these, such as silage harvesters or a mower and large baler. Shelterbelts however usually need to be seven meters wide to accommodate these. The economics of Mxg production are dependent, as with any form of cropping, on end use and present gross margin estimates are based on its low-end value of US$75 per ton if used as straw replacement or for burning in power stations. The economics would be improved if on-farm renewable diesel production could be developed.

In the context of the food versus fuel debate, a holistic viewpoint would be that monoculture is detrimental to creating a sustainable farming system and a mixed farming system is preferable.[19] Whether bioenergy production takes the road of diverse pastures, and its associated biodiversity benefits incorporates bioenergy shelterbelts into the farming system, or continues down the road of monocultures with no shelter will be determined ultimately by market forces and perceived income benefits, which in the absence of government incentives, are unfortunately likely to be short term.

Summary

Mxg is an economically viable bioenergy crop to grow, but achieving high yields—calculated at 30 t DM ha^{-1}—is dependent upon a regular supply of water (more than 500 mm during the growing season). This dependency has caused Mxg to become reliant on irrigation in areas of low summer rainfall and in areas that are dependent upon this irrigation to sustain intensive agricultural production. The economics of Mxg production are such that it is not, at present, economic to install irrigation solely for its production.

Areas dependent upon irrigation that use center-pivot irrigators are devoid of shelter due to center pivot height restrictions. Shelterbelts confer benefits to the farming system that improve its long-term sustainability as well as delivering yield benefits to the existing cropping systems. Although these benefits are difficult to quantify, research shows that they are real. Mxg is a means of creating shelter where center pivots are used due to its ability to allow the pivot to pass through it.

Shelterbelt creation is not solely a benefit in irrigated farming systems. A key outcome of the use of bioenergy crops, such as Mxg, for shelterbelt creation is that the loss in income from growing the shelterbelts on productive agricultural land is compensated for by the value of the biomass produced from the newly created shelter, the improved yield of existing crops, and additional ES benefits resulting from shelter effect and habitat creation.

Furthermore, as well as increasing farm income and sustainability, the external costs to the farm operation are reduced.

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Previous research suggests that integrated farming systems have the potential to improve the energy and GHG balances and biodiversity compared to both organic and conventional systems.

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