PERENNIAL ENERGY CROPS: GROWTH AND MANAGEMENT

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Summary

The production of biomass for energy purposes on agricultural land is an important way to generate renewable energy, and energy crops will probably be grown on a significant and increasing fraction of agricultural land in Europe and worldwide. Among the energy crops, particularly perennial grasses and trees could contribute substantially to alleviation of global problems in climate change and energy security, if high yields can be achieved.

Miscanthus and *Salix* are frequently regarded as front-runners in the search for commercially viable perennial energy crops as they are high yielding, can cope with a range of soils and climate conditions, and have a productive life of 15 to 20 years. This chapter briefly describes growth, management and breeding aspects of perennial energy crops, in particular *Miscanthus* and *Salix*. In addition, environmental aspects including influence of perennial crops on soil and biodiversity are discussed.

1. Introduction

Energy consumption worldwide has increased much faster than the increase in population size. Global problems due to climate change and energy security have greatly increased the interest for renewable energy including energy crops grown on agricultural land. In addition, economic evaluations have revealed that energy crop cultivation has the potential to offer farmers a profitable alternative to frequently declining returns from conventional land use. Thus, a significant and increasing fraction of agricultural land in Europe and worldwide is likely to be dedicated to the culture of energy crops in the near future. There is a great challenge and concern, that cultivation of energy crops might reduce land availability for feed and food production. However, experience shows that energy crop production for existing markets does not necessarily come at the expense of food crops and that it even may contribute to improve food security (FAO 2008).

2. Types of Energy Crops

2.1. Annual and Perennial Energy Crops

Today, annual crops, i.e. crops grown for one growing season such as maize and wheat, contribute greatly to bio-energy worldwide, but yields of these crops are highly dependent on high N inputs into soils. In contrast, perennial grasses and tree crops, i.e. crops with a life span of more than 2 yr, can achieve higher biomass yields with relatively lower inputs of nitrogen fertilizer and are regarded as most efficient nitrogen users. This difference greatly affects energy balance, i.e. energy input per harvest, and life-cycle analyses of bio-energy chains for the different crops, because the production of nitrogen fertilizers is very energy intensive.

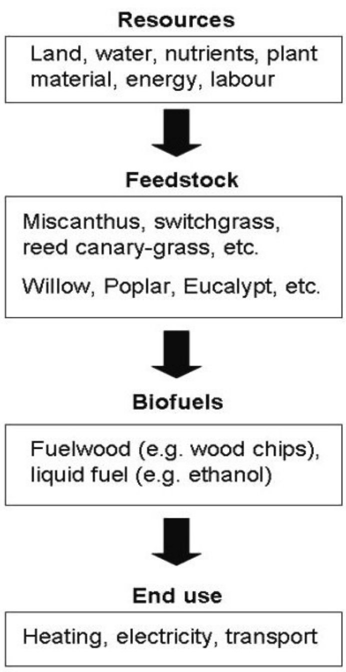

Figure 1. Perennial biomass crops – from feedstock to end use.

Energy crops are generally grown for two different markets, i.e., solid bio-fuels for heat and power generation on one hand, and liquid transport fuels on the other hand (Figure 1). Regarding the transport sector, so-called first-generation bio-fuels such as bio-diesel and bio-ethanol (mainly produced from annual crops such as oilseed rape and cereals) dominate the bio-fuel sector today. A shift towards second-generation bio-fuels, produced from mainly ligno-cellulosic biomass (mostly perennial crops such as *Miscanthus* and *Salix* grown in short rotation), is expected for the future. This shift will greatly affect not only agriculture, but also industry. For example, the development of perennial biomass crops has been stated to be the major driver for the cellulosic ethanol industry.

2.2. Perennial Crops for Warm and Cool Climates

The greatest potential for high biomass yields of perennial energy crops is in areas with warm and humid climatic conditions supporting rapid plant growth, e.g., many warm-temperate, sub-tropical and tropical climates. Most appropriate crop species to be grown under these climate conditions are perennial grasses such as *Miscanthus* and sugarcane, but also fast-growing trees such as eucalypts and poplars.

Also cool-temperate and boreal floras include fast-growing perennial species that are suitable for energy plantations in high-latitude regions, where particularly the frequent occurrence of frost during winter sets limits for the culture of many otherwise high-yielding crops. Particularly tree species of *Populus* and *Salix*, but also grasses such as reed canary grass are suitable crops under these conditions, and they are used as energy crops in northern Europe and North America.

Miscanthus and *Salix* are often regarded as front-runners in the search for commercially viable perennial biomass crops, as they are relatively high yielding, can cope with a range of soils and climate conditions, have relatively few pests and have a productive life of around 15 to 20 yr.

Miscanthus and *Salix* represent two different growth habits and life forms, i.e., grasses and trees, which has major implications for the choice of production system and management. For example, harvest of grasses is often performed with mowers that are common in conventional agriculture, whereas tree harvest often requires specialized machinery (see Section 4.2 below).

Among the energy crops currently discussed for large-scale biomass production on agricultural land in many regions of the world, *Miscanthus* and *Salix* are selected here to represent the two major groups of perennial energy crops, i.e. grasses and trees.

This chapter briefly characterizes mainly these two species – they may stand for many other crops of similar life form and appearance – with respect to their potential use as energy crops on agricultural land and gives an outline of the appropriate production systems and management actions required to achieve high biomass yields. In addition, breeding issues of these perennial crops and critical environmental concerns associated with their culture are addressed.

3. Species

There are a number of perennial plants (grasses and trees) with a great potential as energy crops and with regionally greater potential compared to *Miscanthus* and *Salix*. The most prominent example is probably sugarcane (species of *Saccharum*), which is the basis for the production of liquid transport fuels (ethanol) in Brazil. Several other C4 perennial rhizomatous grasses, e.g. switchgrass (*Panicum virgatum* L.), species of *Cyperus* and *Spartina* and - not least - fast-growing bamboos (various species within the family Poaceae) are interesting alternatives for biomass production in warm-temperate and tropical regions.

Reed canary-grass (*Phalaris arundinacea*) is an example for a robust perennial C3 grass, widely grown across temperate regions of Europe, Asia and North America, where it is currently tried as energy crop on agricultural land in some regions, like in Sweden and Finland.

Among the trees, some species can be grown in short rotation on agricultural land and are therefore potentially interesting energy crops for agriculture. Apart from *Salix*, poplars and aspens (species of *Populus*) have a great potential as energy crops in temperate and boreal agriculture, whereas fast-growing eucalypts (species of *Eucalyptus*) are sensitive to frost and therefore confined to warm-temperate and tropical agriculture.

Only *Miscanthus* and *Salix* are presented here more in detail, but production systems and general management issues for many other energy crops are not principally different from these two species. For example, poplars and aspens are currently much more important for biomass production than willows in many regions of Europe and North America, but production systems and management of poplars for energy purpose is very similar to willow, especially when grown in short rotation.

3.1. *Miscanthus*

Miscanthus species are tropical and subtropical grasses native to southeastern Asia, China, Japan, Polynesia and Africa. Cultivars of *M. sacchariflorus, M. sinensis,* their hybrids, and other *Miscanthus* species are frequently grown as ornamental crops. The genotype with the greatest biomass potential is a sterile hybrid (*Miscanthus x giganteus*), likely of *M. sacchariflorus* and *M. sinensis* parentage.

Miscanthus species are similar in appearance to some types of bamboo, although they are more closely related to sugarcane. They produce a new canopy of tall canes each year. In their region of origin, the canes can reach a height of 7 to 10 m, whilst in Europe heights of around 4 m are more common (Fig. 2). They have a rigorous root and rhizome system that can penetrate to depths of 1 m or more. The very high potential yield of *Miscanthus* is due partially to its C4 photosynthetic pathway, which is similar to other plants of tropical origin such as maize, sugarcane and sorghum. Compared to the C3 photosynthetic pathway, which is common for most agricultural crops native to the temperate zone (e.g. wheat), the C4 photosynthetic pathway typically enables the plants to employ a more efficient carbon fixation process, particularly when grown under warm and droughty conditions.

Although having evolved in regions experiencing warm temperatures and high precipitation, *Miscanthus* has been grown successfully in temperate regions and has demonstrated an above ground tolerance for light frost conditions. Leaves and shoots are destroyed below approximately -5^{o}C, but the plants can overwinter as rhizomes at considerably lower temperatures. In comparison to most crops native to temperate climates, the temperature requirements to break winter dormancy of the tested *Miscanthus* genotypes are very high, which strongly limits productivity in temperate regions by means of greatly delayed spring emergence and growth. Delayed spring growth in combination to frost sensitivity are likely to be the major limiting factors for *Miscanthus* culture in environments with short growing seasons and cold winters.

Figure 2. *Miscanthus giganteus* is a rhizomatous grass that can be grown in very dense stands, here at Woburn Experimental farm, Rothamstead Research, UK (Photo: A. Riche, Rothamstead Research)

In Europe and North America, *Miscanthus* cropping was tried since the late 1990s in field experiments to investigate agronomic problems such as plant establishment, nutrient supply, yield development and biomass properties. Mean harvestable biomass yields over several harvest years are frequently reported at around 10 to 15 tons ha^{-1} yr^{-1}, although figures beyond 20 tons ha^{-1} yr^{-1} were also reported. Compared to many annual crops, *Miscanthus* cropping has also been reported to enhance the nutrient cycling in the plant–soil system. For example, as a result of high inputs of leaves, rhizomes and roots, increased concentration of organic carbon and total nitrogen have been demonstrated.

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Biographical Sketch

Martin Weih, PhD, is a Professor of crop eco-physiology at the Department of Crop Production Ecology at the Swedish University of Agricultural Sciences (SLU) in Uppsala. He has more than 15 years of experience in ecological research on birch, willow, poplar, bamboo and other species. His main interest is in plant eco-physiology and ecological questions related to biodiversity. Major research activities focus on the production ecology and physiology of energy crops - mainly perennial biomass crops such as *Salix* and *Populus* grown on agricultural land - and the genetic basis of production traits. Effects of plantations of fast-growing trees on the environment (e.g., biodiversity) and landscape are another important research interest. He is participating in several EC projects. Author of more than 55 peer-reviewed publications in scientific journals and books.