Technical University of Denmark

Biomass production in new sustainable multipurpose cropping systems

Jørgensen, U.; Østergård, Hanne

Published in:
Risø energy report 2. New and emerging bioenergy technologies

Publication date:
2003

Document Version
Publisher's PDF, also known as Version of record

6.1 Biomass production in new sustainable multipurpose cropping systems

UFFE JØRGENSEN, DANISH INSTITUTE OF AGRICULTURAL SCIENCES (DIAS), AND HANNE ØSTERGÅRD, RISØ NATIONAL LABORATORY

Biomass production

This chapter mainly concerns the production of lignocellulosic biomass for generating heat and power. To date, such material has been available almost exclusively in the form of surplus or waste biomass from forestry or agriculture. However, as the demand for renewable energy increases to fulfil the ambitious goals of the EU's White Paper on renewable energy, new ways to increase biomass production from energy crops need to be developed.

Furthermore, there is a general demand within the EU for sustainable crop production characterised by reduced inputs of pesticides and chemical fertilisers, reduced nitrate leaching and increased agro-biodiversity. The challenging possibility now exists of developing new, efficient, energy-crop systems based on these principles. Compared to existing cropping systems, these new systems also have to show a clearly positive energy balance.

One obvious place to grow energy crops is on set-aside land – defined by the EU as land that is available for agriculture but not currently used to grow food or fodder crops. Across the EU, set-aside accounts for 10% of the area used for grain or oilseed crops. Denmark has about 200,000 ha of set-aside, which could produce 33 PJ/y (lower heating value) if used for energy crops with an average yield of 10 t/ha dry matter.

Energy crops

Many different crops can produce biofuels for heating, power and transport. The European Energy Crops Overview showed that more than 30 species had been tested as energy crops (Venendaal et al., 1997).

Conventional crops such as wheat, rye, triticale and sweet sorghum have been used as energy crops (Table 7), with the advantage that farmers already know how to grow them. Current thinking, however, is that it is not a good idea to grow grains as dedicated energy crops . The problem is that these crops require higher input and annual ploughing, which leaches nitrates and other nutrients from the soil (Jørgensen & Mortensen, 2000).

Instead, much recent research in Denmark and the rest of the EU has looked at perennial energy crops such as willow, poplar, alder, giant reed, *Miscanthus* and cardoon (Jørgensen & Schwarz, 2000).

Compared to traditional crops, the perennials need lower inputs (Venendaal et al., 1997; Jones & Walsh, 2001) and pose much less risk of nutrient leaching (Jørgensen & Mortensen, 2000; Aronsson & Bergström, 2001). Biomass from perennial crops contains lower levels of nutrients, which means more efficient use of nutrient input and better combustion characteristics (Jørgensen & Sander, 1997; Jørgensen & Schelde, 2001).

Promising as the perennial energy crops are, they are still relatively new and do not benefit from the centuries of selection and breeding associated with conventional crops. Much progress in improving yield and quality remains to be made through better breeding and crop management.

Another 'new' perennial energy crop, switchgrass, has been studied extensively in the USA. Switchgrass is indigenous to the US prairies, where it is grown to reduce

Table 7. The most popular energy crops in Denmark and the EU (Venendaal et al., 1997). No new inventory of European energy crop area has been done since 1996.

Common name	Annual/perennial	Hectares in Denmark, 2002	Hectares in EU, 1996
Oilseed rape	A	19,973	800,000
Willow	P	834	18,000
Winter wheat, winter rye, triticale, spring barley	A	0	9,400
Miscanthus	P	30	170
Reed canary grass	P	0	4,050
Poplar	P	9	550
Sunflower	A	–	91,000
Sugar beet	A	–	6,250
Hemp	A	–	350

6.1

soil erosion and to create wildlife habitats. More recently, a large research project combining physiology, plant breeding and crop management has shown that switchgrass has a promising future as an energy crop[2] (Sanderson et al 1996).

Like *Miscanthus*, switchgrass benefits from the more efficient "C4" photosynthesis compared to the "C3" photosynthesis used by most common crops. Switchgrass is easy to establish from seeds, and varieties suited for different climates are available.[3] Switchgrass has recently been tested under European conditions as part of an EU project.

Breeding for productivity and quality

Swedish experience with willow has shown that exploiting the genetic resources of a "new" crop species through careful breeding can create big improvements in a short time. The latest willow varieties commercially available from the breeding company Svalöf Weibull, for example, show yields 63% higher than the reference variety, which itself was the best available when breeding began in 1987.[4]

In other species the genetic pool remains largely untapped. In *Miscanthus*, for example, nine different genotypes showed a 2.4-fold difference in radiation conversion efficiency (the ability of the plant to convert energy from the sun into dry matter) (Jørgensen et al., 2003a). It is reasonable to assume that in the long term better breeding of *Miscanthus* could double its current yield of biomass.

Willow can be burned in existing wood-fired energy plants, and *Miscanthus* can be used directly in plants designed to burn either straw or wood. In the long term, however, it may be possible to reduce the capital costs of bioenergy plants by taking advantage of the special properties of these new crops.

One example of this relates to the concentration of chloride and potassium salts in biomass. Straw contains a lot of these salts, which can cause corrosion and slagging problems. The need to make power plants from corrosion-resistant materials has increased the cost of energy from straw, at least in Denmark.

Another solution to the corrosion problem is to use crops with a lower salt content (Jørgensen & Sander, 1997). Compared to straw, *Miscanthus* contains lower concentrations of salts, and some varieties are particularly low in salts (Figure 7). Future programmes of breeding or genetic modification could yield *Miscanthus* strains with optimal combustion qualities (Atienza et al, 2003).

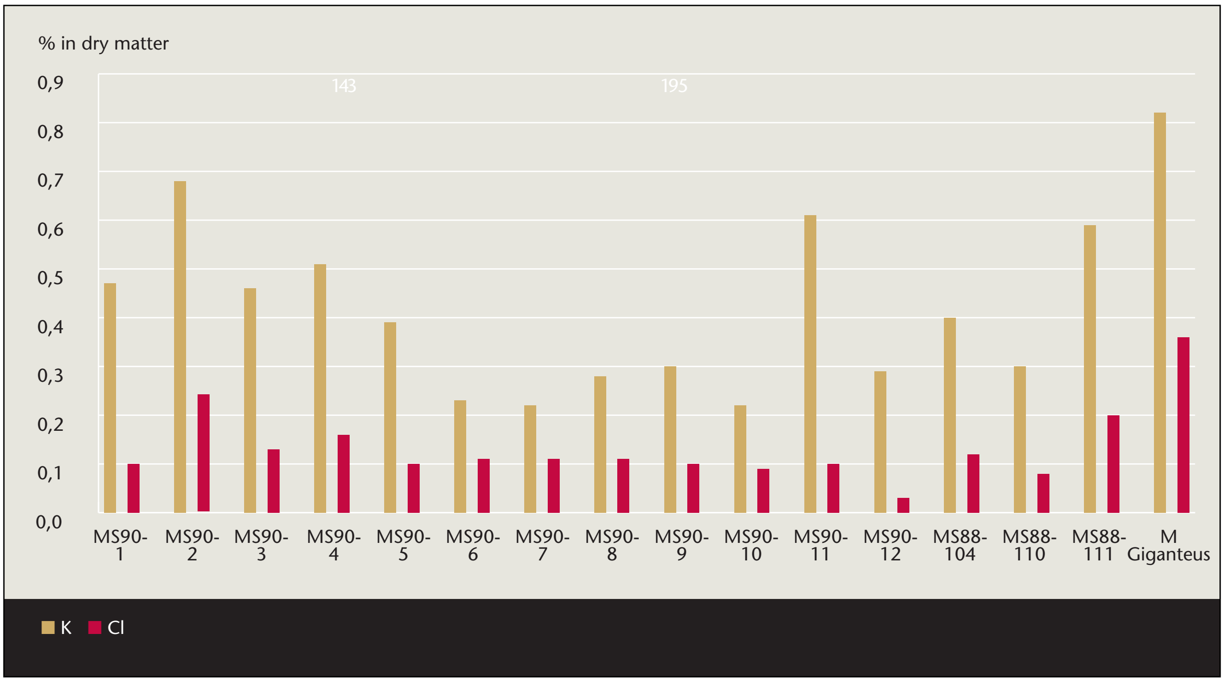
Another way to beat the salt problem may be to convert the biomass into liquid biofuels instead of burning it (section 6.4).

[2] For details of the potential commercial use of switchgrass in large US bioenergy projects, see for example: www.state.ia.us/dnr/energy/programs/switchgrass/switchgrass.htm and http://bioenergy.ornl.gov/papers/misc/switgrs.html

[3] see www.switchgrass.nl/index.htm

[4] www.agrobransle.se

Figure 7. Salt content (potassium and chloride) of 15 *Miscanthus* genotypes grown in Denmark, measured at spring harvest over three years (Jørgensen, 1997). One genotype has just 10% of the chloride content of some other varieties.



6.1

Cropping systems for energy crops

Making use of diversity within a single crop, intercropping of different species and crop rotation are all ways to increase both yields and the efficiency of resource use (Finckh and Wolfe, 1996).

For example, it is well-known that mixtures of cereals generally stabilise yields, reduce losses due to disease, so less fungicide is needed, and buffer abiotic stresses compared to pure stands of individual cereal varieties (Finckh et al 2000). Similarly, planting mixtures of willow varieties increases yields and reduces attack by rust disease (McCracken and Dawson, 1998).

Fast-growing short-rotation coppice crops also need less herbicides than many other crops because once they become established they out-compete weeds. Willow or poplar crops can be provided with nitrogen without the need for artificial fertilisers by intercropping with nitrogen-fixing plants such as clover or lupins (Granhall 1994).

Alder is especially interesting because it is one of the few woody crops in our northern climate that can fix its own nitrogen, which it does through symbiosis with the microorganism Frankia. Alder has been used in a "combined food and energy system" that integrates energy and food crops on the macro scale in an organic production system (Kuemmel et al. 1998).

There is a need to develop new intercropping systems designed especially to produce biomass for bioenergy. An example is the growing of winter legumes, followed by maize as a summer crop. This has many advantages with respect to yield and minimal use of nitrogen fertiliser (Karpenstein-Machan and Stuelpnagel 2000). Both crops may be used in biogas plants, and the nutrients subsequently recycled to the farm.

Energy balance and global greenhouse gas balance

A prerequisite for an efficient and profitable energy crop is a positive energy balance. This means that when the biomass is converted to energy, this energy output has to be larger than the energy input needed to grow and harvest the crop, taking into account the energy costs of crop management, such as pesticides, chemical nutrients and machinery.

Energy balance is influenced by the cropping system. Table 8 shows energy balances for four energy crops – willow, *Miscanthus*, rye and oilseed rape – grown as monocrops by conventional farming in Denmark. All four show a large positive energy balance when the whole crop is used for energy.

For the crops in Table 8, the highest energy input is inorganic nitrogen fertiliser. Annual crops need about twice as much fertiliser as the perennial crops, so it is not surprising that the annuals rye and rape show lower energy balances than the perennials willow and *Miscanthus*. In the future it might be possible to use nitrogen-fixing alder in an organic cropping system (Jørgensen et al., 2003b). This would need only about half the input energy required by willow, so the ratio of energy output to input would rise to around 30.

One study made a detailed comparison of all energy aspects during the life cycles of two well-known bioen-

Table 8. Energy budgets for four crops delivered to the plant gate (GJ/ha/year). From Jørgensen & Kristensen (1996).

	Willow	Miscanthus	Winter rye	Winter rape
Yield (tonne dry matter/ha/y)	9	9	10	3 seed 2.6 straw
Dry matter %	50	85	85	91 seed 85 straw
Seeds, fertilisers, pesticides	5.3	4.9	11.2	11.5
Soil tillage, crop care	0.2	0.2	1.7	2.6
Harvest, storage and delivery	3.0	2.1	2.1	1.5
Indirect energy (machines, buildings etc.)	1.7	1.6	3.1	3.8
Fossil input total	10.3	8.8	18.1	19.4
Energy output (lower heating value)	147	161	171	116 (whole crop)
Output/input	14	18	10	6

6.1

ergy crops – short-rotation coppice willow and *Miscanthus* – and low-input mixed indigenous coppice wood with longer rotations. The conclusion was that if land area is the limiting factor, short-rotation coppice willow and *Miscanthus* give better results (Lettens et al 2003). However, this depends among other things on the fact that at present *Miscanthus* is almost free of pests and diseases. If *Miscanthus* is grown over large areas this situation could change, with negative consequences for its energy balance.

As well as providing energy, biomass is important for its ability to mitigate the greenhouse effect. Biomass provides energy without increasing the net amount of carbon dioxide in the atmosphere; if it replaces fossil fuel, then the amount of carbon dioxide falls. The performance of biomass in this respect is often measured simply by the amount of fossil fuel it replaces, but the truth is more complex.

In fact, different energy crops yielding similar amount of energy can show significantly different global greenhouse gas balances. This is because the global greenhouse gas balance takes into account carbon sequestration in the soil, as well as emissions of other greenhouse gases such as nitrous oxide and methane.

The large amount of straw used for energy in Denmark has recently been questioned because of its negative effect on soil carbon and soil quality (Christensen, 2002). Another study calculates that the annual crop triticale and the perennial *Miscanthus* may show differences of 30–70% in global greenhouse gas reduction when they replace identical amounts of fossil fuel (Olesen, 2002). The total emission reduction was calculated as 355–447 kt CO_2 equivalents/y for *Miscanthus* and 265 kt CO_2 equivalents/y for the same energy yield of triticale (Table 9).

These differences will become increasingly important when the Kyoto Protocol's Article 3.4 on land use effects comes into operation.

Further environmental perspectives

Biomass feedstocks are low-value bulk products. To make energy crops competitive with food and fodder crops, they need to provide other significant societal benefits. One example concerns water.

Water protection is a major environmental issue in Europe, and European agriculture struggles to meet the demands of the EU Directive on nitrates. Perennial energy crops have deep, permanent root systems, a long growing season and do not require the soil to be tilled for many years. These factors mean that after the first year, levels of nitrate in water percolating from the root zone are very low (Figure 8).

Total nitrate leaching from perennial energy crops on sandy soils in Denmark is estimated at 15–30 kg N/ha/y (Jørgensen & Mortensen, 2000) compared to about 75 kg N/ha/y as an average for conventional food and fodder crops. Water quality from perennial energy crops is further improved by the fact that these crops have very low pesticide requirements. In part this is because pests and diseases do not usually affect the quality of energy crops, and so do not need to be treated.

Recycling wastewater and other effluents by using them in agriculture is another worthy environmental technique that is often not used because of the risk of contaminating food products. This risk is reduced if the effluent is used on energy crops (Aronsson and Perttu, 2001), which are also very efficient at taking up nutrients mineralised from organic wastes. In Sweden more than 30 willow plantations are now used to recycle landfill leachate and domestic wastewater.

Some willow clones are quite efficient at taking up cadmium, and so may help to rid the soil of this unwanted metal. Cadmium enters the soil mainly in phosphate fertiliser (Eriksson et al., 1996), and can cause health problems even at low levels (Alfvén et al., 2000).

A fascinating feature of cadmium uptake by energy crops is that during combustion, careful control of the temper-

Table 9. Land area required in Denmark to produce 5 PJ-worth of biomass in triticale and in *Miscanthus* (harvested November or April). Figures for nitrous oxide emissions, energy consumption, fossil fuel substitution and carbon sequestration are compared with those for conventional cereal production using standard IPCC methodology (Olesen, 2002).

	Triticale	Miscanthus November	Miscanthus April
Area required for production of 5PJ (ha)	32140	24812	32797
Nitrous oxide emission reduction (kt CO_2 equivalents/y)	20	30	36
Soil carbon sequestration (kt CO_2 equivalents/y)	–45	37	108
Reduced energy use (kt CO_2 equivalents/y)	5	3	18
Substitution of fossil fuel (kt CO_2 equivalents/y)	285	285	285
Total emission reduction (kt CO_2 equivalents/y)	265	355	447

6.1

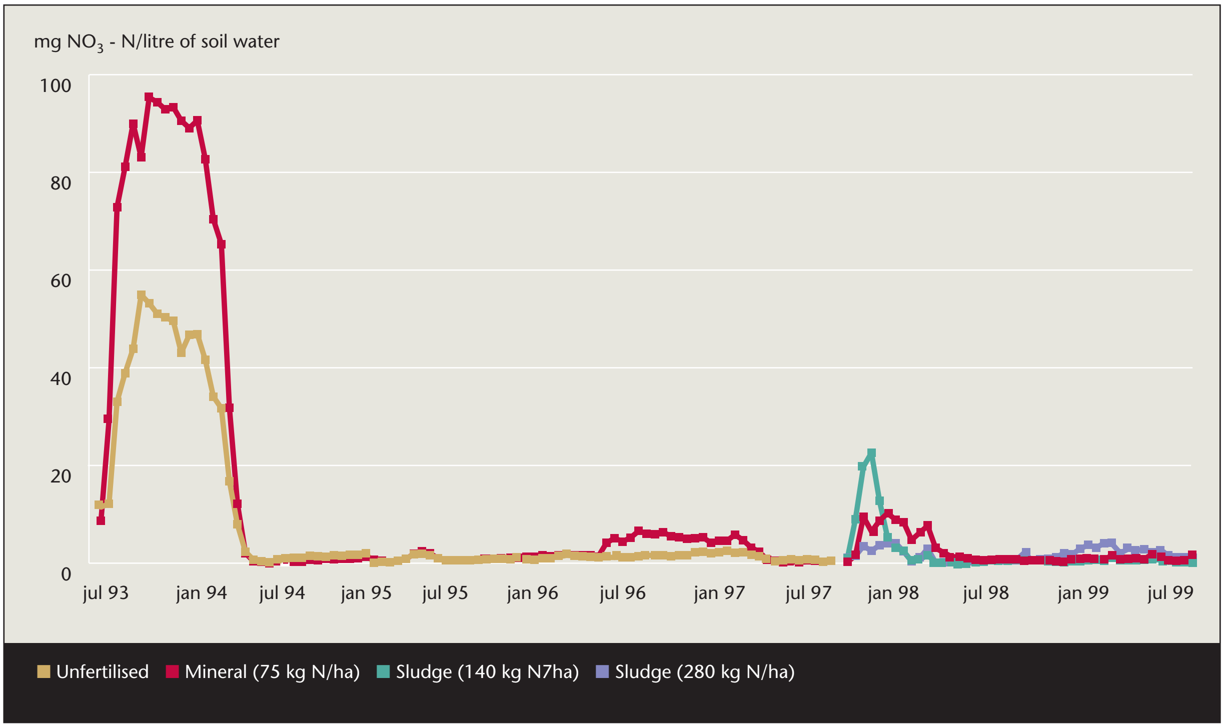
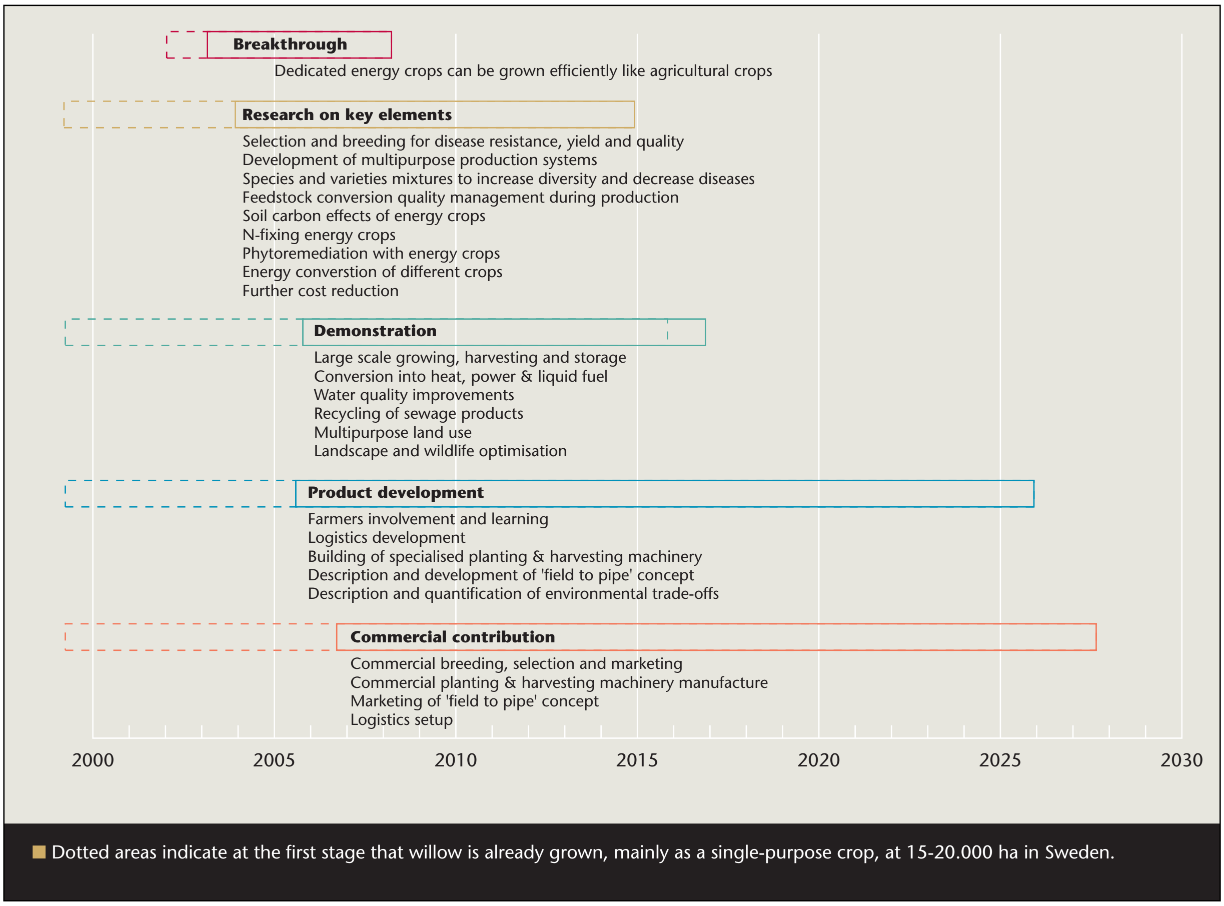


Figure 8. Nitrate measured as nitrogen in coarse sand below the root zone of willow at Jyndevad Research Station in Denmark. The treatments were: unfertilised, mineral fertiliser applied annually and municipal sludge applied in 1997 at two levels (Jørgensen & Mortensen, 2000).

Figure 9. Time scale from breakthrough to commercial contribution



6.1

atures in boilers and cyclones can concentrate the cadmium in a small fraction of the ash (Dahl & Obernberger, 1998). In this way cadmium may be extracted for re-use or disposed of in a small volume of ash.

These studies indicate that growing perennial energy crops may be a real win-win solution, delivering not only renewable energy but also clean water, better recycling and carbon sequestration in soils. However, some of these effects need further documentation and development. There is, for instance, still only very limited information on the long-term effects of energy crops on soil carbon levels (Mann and Tolbert, 2000) and on nitrous oxide emissions.

Conclusion

Using energy crops to produce electricity is an effective way to mitigate the greenhouse effect, mainly through the replacement of fossil fuels. Energy crops are a sustainable energy source, and they increase energy security by reducing the demand for coal and oil, most of which comes from outside Europe. They also have other environmental advantages, such as reducing nitrate pollution and absorbing heavy metals.

The available resources of surplus biomass will soon be used up, but the growth in demand for renewable energy will almost certainly not stop there. The future is likely to see much greater use of perennial energy crops, which have many environmental and other advantages as part of a renewable energy system.

However, dedicated energy crops are quite different from conventional agricultural crops, and they are low in value. Farmers are unlikely to grow them unless a clear policy provides them with some degree of economic security.

Both farmers and the energy industry need clear signals from governments on the future of bioenergy, so that they can plan long-term investments in crops, machinery and power stations.

The whole energy crop chain should also be analysed for administrative and legislative bottlenecks that may hamper commercial development.

Finally there is a need for further breeding of specific energy crops with higher energy contents, lower energy inputs and optimised quality for downstream processing; for new intercropping systems with high resistance to pests and diseases; and for further R&D on cost reduction and environmental optimisation of the complete production chain.