Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2011, 7 (2), 205-210

Cultivation, Harvest and Storage of Short Rotation Coppice - Long-Term Field Trials, Environmental Effects and Optimisation Potentials

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Received (Geliş Tarihi): 08.05.2011 Accepted (Kabul Tarihi): 09.07.2011

Abstract: Currently 4 % of the total energy consumption of Europe is covered by biomass from agriculture and forestry. This share shall increase to 20 % or 220 10^6 ton of oil equivalents (MtOE) in 2020. Such an extension of biomass production would comprise 15 % of the arable land in the EU and hence, the question arises whether this energy resource can be exploited sustainable or not. It is assumed that using energy crops such as short rotation coppice (SRC) as resource increases biodiversity and farmer sources of income. In order to identify crop species for sustainable energy farming it is necessary to determine the significance of genetic, environmental and growing-technical factors. Therefore, in 1994 a long-term practical oriented field experiment on a sandy soil was established to investigate ten annual and perennial plant species and the effects of the different N fertilisation. The measuring programme includes yields, energy gain, N_2O emissions as well as ecologically relevant plant and soil constituents. The results of this 15-year trial confirm the possibility of ecological and energy-efficient production of various energy crop species. Furthermore, several potentials for optimisation of the whole agricultural production chain for SRC have been identified. Different harvesting technologies are available at industrial scale. Using common technology, energy losses of 10 to 25 % during storage have to be accepted due to the high water content of the wood at harvest time and the short cutting length produced with these chopping systems. Therefore, a prototype of a tractor mounted chopper for SRC has been designed and tested at ATB. The system is designed to produce oversized wood chips for optimised inherent drying. Thus, mass and energy losses during storage can be reduced significantly as well as mould growing can be minimised.

Key words: Energy crop, yield, nutrients, nitrogen, emission, N_2O, energy balance, harvest, short rotation coppice

INTRODUCTION

The generation of bioenergy has a key role in current EU strategies in order to contribute increasingly to climate protection and energy security. Energy from biomass offers considerable potential to fulfil these targets due to a wide variety of feedstock, especially energy crops, and conversion technologies. Energy farming on surplus agricultural area presents an opportunity to create alternative income sources besides food production, to strengthen added value and employment in rural areas. In general, energy crops should have characteristics like high yields, low production inputs and high energy values to make the production of energy from biomass even more economically efficient and to optimise the environmental benefits.

MATERIALS and METHODS

In order to select environmentally friendly plant species an experimental field was established Northwest of Potsdam on a loamy sand soil. The field is divided in 10 long plots of 0.25 ha, which are subdivided in 4 blocks with 624 m^2 each. Block A receives basic mineral fertilisation and 150 kg N/ha. On blocks B and C, wood- and straw ashes as well as

75 kg N/ha each are applied. Block D is not fertilised. On the entire area, no plant protection products are used (Fig. 1). As fertilisers, 540 or 270 kg/ha of calcium-ammonium nitrate and 520 kg/ha of potash-magnesia/super-phosphate mixture, as well as 660 kg/ha of coarse ashes each from a wood- and a straw combustion plant are used (Scholz et al., 2001; Scholz and Ellerbrock, 2002).

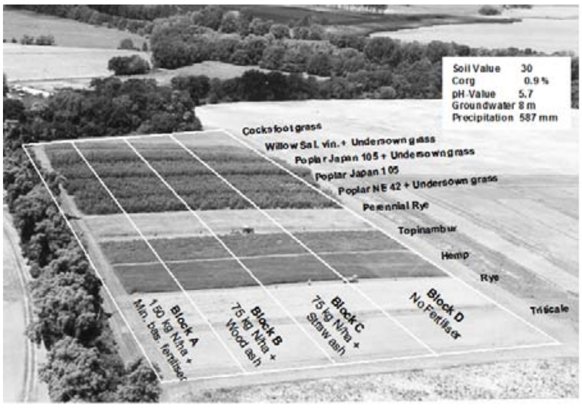

Figure 1. Experimental field at the ATB

RESULTS and DISCUSSION

Yield

The yield is the most important parameter determining the environmental and energetic efficiency of the production of energy crops. Related to the measuring period of 8 to 15 years the highest dry matter (DM) yields in total were measured on the poplar plot Japan 105 (9.1 - 10.1 tDM/ha). The undersown grass reduces the average yield by 10 to 25%. On the intensively fertilised blocks (A), hemp, rye, and triticale achieve with 8.3 to 9.8 tDM/ha acceptable whole-crop yields too. The originally promising topinambur haulm (Jerusalem artichoke) shows the lowest yield of all crops (Table 1).

The reduction of nitrogen fertiliser causes a loss of yield in all haulm-type crop species. In relation to the conventional N application rate of 150 kg N/ha the yields of rye and triticale decrease by approximately 10 to 15% at 75 kg N/ha, and the complete omission of fertiliser leads to a loss of 30 to 40% after 15 years. In contrast to these crops, the yields of SRC were reduced only within the first 5 to 10 years. Later there is nearly no difference between the blocks. The reasons of this ecologically very useful phenomenon are not clarified up to now (Fig. 2).

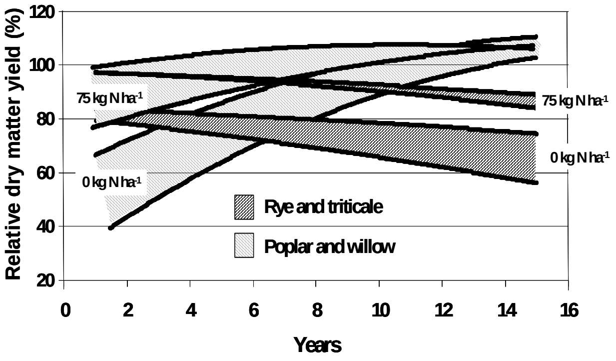

Figure 2. Development of SRC and cereal yield depending on N application rate. (100% yield at 150 kg N/ha)

Even though the use of plant protection products was consistently dispensed with, pest infestation and plant diseases stayed within limits and did not cause any detectable yield depression. Since weeds are usually harvested as total with the energy plants, yield losses in comparison with a weed-free culture are insignificant (Karpenstein-Machan, 2000.)

Table 1. Average dry matter yield of the investigated energy crops from 1994 to 2009

Plant species	Number of years (y)	Dry matter yield (t/(ha y))			
		Block A 150 kg N/ha	Block B 75 kg N/ha	Block C 75 kg N/ha	Block D 0 kg N/ha
Cocksfoot grass	10	8.0	7.2	7.3	5.4
Willow*, Salix 21	14	8.1	7.1	8.0	7.1
Poplar*, Japan 105	14	7.8	7.9	8.7	7.6
Poplar, Japan 105	14	9.9	10.0	9.5	10.1
Poplar*, NE 42	10	5,4	6.5	6.9	6.9
Perennial rye	5	8.5	8.0	7.4	6.1
Topinambur	7	4.2	4.1	3.9	3.3
Hemp	8	9.8	9.1	9.0	7.5
Winter rye	15	8.7	8.1	7.9	6.7
Winter triticale	9	8.3	8.0	7.8	6.0

* with undersown grass

Environmentally Relevant Plant Nutrients

The environmental relevance of plant nutrients results from both the ecological effects of the fertilisers on the plant and the soil and the emissions during combustion. In order to minimize detrimental effects, different regulations provide limits for environmentally harmful nutrients and heavy metals.

The nitrogen plays an important part in this context because its surplus enters in the ground water and so causes the eutrophication of water and because it emits nitrogenous oxides during cultivation and combustion. The contents of nitrogen (Nt) of the investigated crop species exhibit an extraordinary range of variation. Cocksfoot, grain, and hemp reach the highest average Nt contents (0.9 to 1.9 %). With 0.4 to 0.7 %, the contents of trees and topinambur haulm are considerably lower (Fig. 3).

The contents of sulphur (S) and chlorine (Cl) are within the range of the values given in the literature (Obernberger 1997; Hartmann and Strehler, 1995; Maier et al. 1997). Only the sulphur content of cocksfoot is higher. In addition, this culture is also characterised by very high chlorine content. The winter-annual grain species and hemp also reach rather high values of 0.11 % to 0.14 % sulphur and 0.09 % to 0.13 % chlorine. Among all energy plants, the trees have the lowest contents of approximately 0.05 % sulphur and 0.01 % chlorine.

Fertilizer-Induced Emissions

There are two sources of gaseous emissions caused by fertilisers. The first one are the emissions relevant substances in plants such as nitrogen, phosphorus, sulphur and chlorine. The application of 150 kg nitrogen per hectare causes an average increase in the Nt content of plants of 0.1 to 0.3 % (Scholz and Ellerbrock, 2002). This leads to an increase of nitrous oxide emissions (NO_x) of 10 to 50 mg/m^3 during combustion (Obernberger, 1997), which is significant compared with legal limits in the range from 250 to 400 mg/m^3.

Potassium (P), Sulphur (S) and Chlorine (Cl) also correlate more or less significantly with the amount of fertiliser. During combustion, the sulphur incorporated in the plants enters into the gaseous phase while forming sulphur oxides (SO_2 and SO_3). Depending of combustion conditions, chlorine can result in chloric acid (HCl), different chlorinated hydrocarbons (CHC), and highly toxic polychlorinated dibenzodioxines and dibenzofuranes (PCDD/F). Moreover, both elements favour the corrosion of the heat exchanger pipes in the boiler.

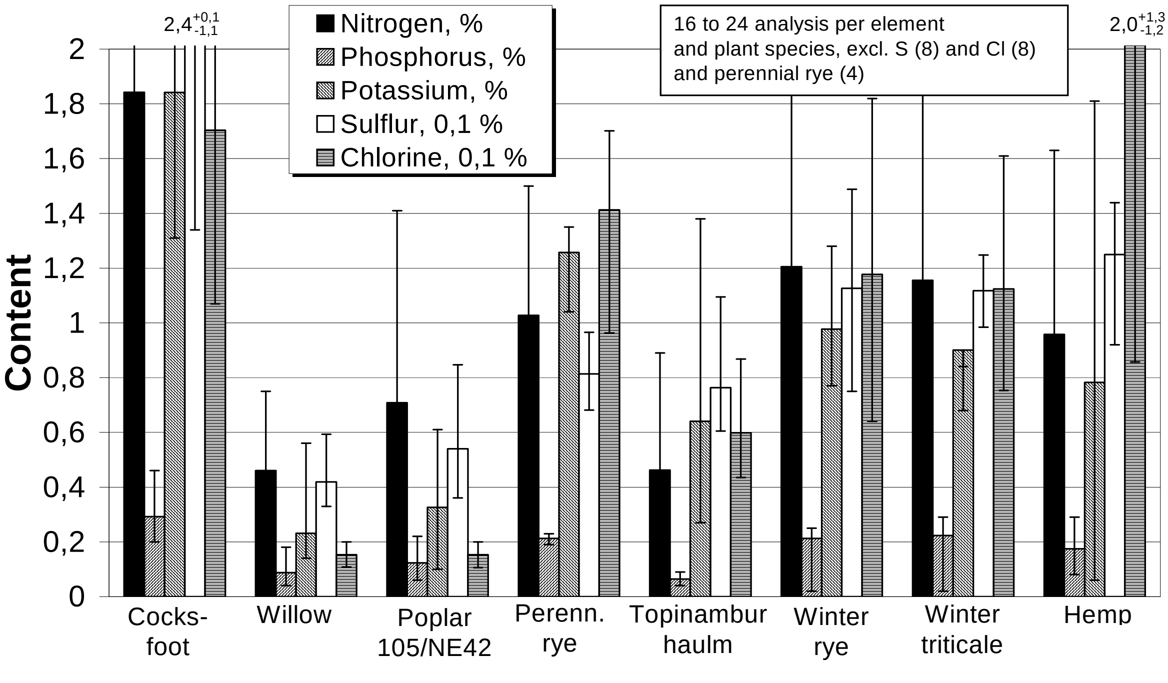

Figure 3. Contents of relevant macro- and micro-nutrients in the investigated energy crops

The other source of gaseous emissions caused by nitrogenous fertiliser occurs on the field. As a result of the activity of microorganisms the nitrogen forms nitrous oxide (N_2O), which global warming potential is about 300 times more effectively than CO_2. As shown by gas measurements, carried out on the mentioned experimental field over several years, the application of 150 kg N/ha causes an additional quantity of up to 2 kg N_2O-N per hectare and year to be emitted from the soil (Hellebrand et al., 2003). There is also an influence of the plant species, which partially may be explained by the soil management. Poplar and willow cause significantly less N_2O emissions than cereals (Fig. 4).

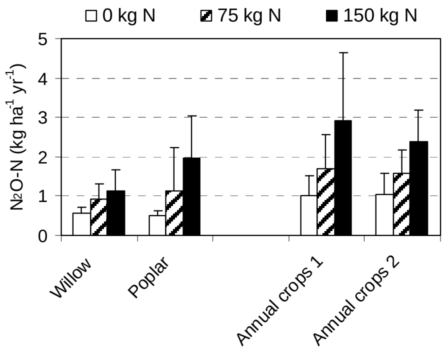

Figure 4. Long-term N_2O emissions of SRC and cereals (1999-2007)

Therefore non-fertilised SRC fields emit only 15 to 30% N_2O of conventionally fertilised cereal fields.

Energy Gain

For the determination of the energetic efficiency and the energy gain of the production and utilization of energy plants, energy requirements and –yields must be established and compared. The cumulated energy demand (ED) is determined using a method which takes all direct and indirect primary energy requirements into account (Scholz et al., 1998).

The energy yield (EY), which is calculated based on the yield, the calorific value, and the water content of the storable plant material, is dependent upon the plant species, the undersown crop, and the fertilisation. If those experimental plants whose yield is extremely low, such as topinambur haulm and field trees with undersown crops, are disregarded, the energy yield ranges from 100 to 190 GJ/(ha y) (Table 2).

In contrast to other renewable energy sources, however, the decisive criterion in the case of energy plants is energy gain rather than the input/output relation because the availability of cultivation areas is limited. Independent of the fertilisation variant, the annual (net-) energy gain (**EG**), which results from the difference of energy demand (**ED**) and -yield (**EY**), ranges between 97 and 178 GJ/(ha y) for grain, cocksfoot, and hemp. With 161 to 172 GJ/(ha y), the poplar clone Japan 105 without undersown grass also achieves rather high energy gains. With the exception of poplar, the energy gain without fertilisation (block D) is only up to 24 % lower as compared with intensive fertilisation (block A). The differences between intensive and reduced fertilisation (block B/C) are even smaller.

Optimisation Potentials

Because of the extremely low need for labour, fertilizers and pesticides connected with a high potential of environmental friendly energy production SRC have good chances to be cultivated in large scale in future. However, the current problem is the lack of well proven and reliable machinery for the production of these novel agricultural crops.

Table 2. Energy yield of energy crops as a function of fertilisation

Plant species	Energy (GJ ha-1 y-1)								
	Block A 150 kgN/ha			Block B/C 75 kgN/ha			Block D 0 kgN/ha		
	ED	EY	*EG*	ED	EY	*EG*	ED	EY	*EG*
Cocksfoot grass	13	141	*128*	8	130	*122*	3	100	*97*
Willow*, Salix 21	10	126	*116*	5	119	*114*	1	90	*89*
Poplar*, Japan 105	10	119	*109*	5	126	*121*	1	112	*111*
Poplar, Japan 105	10	178	*168*	5	166	*161*	1	173	*172*
Poplar*, NE 42	10	85	*75*	5	112	*107*	1	107	*106*
Perennial rye	11	147	*136*	7	133	*126*	2	105	*103*
Topinambur	12	71	*59*	8	68	*60*	2	55	*53*
Hemp	13	191	*178*	9	176	*167*	4	152	*148*
Winter rye	14	154	*140*	9	144	*135*	4	121	*117*
Winter triticale	14	153	*139*	9	151	*142*	5	116	*111*

* with undersown grass, ED: energy demand, EY: energy yield, EG: energy gain

There were a lot of efforts and developments during the past 30 years, but only a few of them were successful for praxis application. At present, forage harvesters with special cutter units for SRC achieve the highest working rates, but they are relatively expensive (>100,000 €) and - including the weight of harvester – quite heavy (>12 t) which may cause difficulties on some soils. At present, there is a growing need for inexpensive harvesting technology for farmers to start with SRC at low risk. Therefore, a lightweight and cost-effective tractor-mounted cutter chipper has been designed and tested at the ATB (Fig. 5).

Figure 5. A new development of a 1 row-tractor-mounted cutter chipper (ATB)

In contrast to forage harvesters which are designed for the production of short chips (5 … 40 mm) this specially designed cutter chipper can produce longer chips between 50 and 100 mm. Main advantages of such longer chips are an improved shelf life, a reduced load of thermophilic fungis as well as reduced dry matter losses and energy losses during storage (Fig. 6) (Scholz et al., 2005).

CONCLUSIONS

The results of a 15 years field trial with various energy crop species on a poor sandy soil in Germany show that fertiliser application can be reduced significantly and pesticides can generally be dispensed with. On high fertilisation level, the mean yields of above-ground biomass range between 4.2 and 9.9 tDM/ha. Hemp, poplar and whole crop cereals reflect the highest yields. If fertiliser application is reduced from 150 to 75 kg N/ha, the yield diminishes by 10 to 15% after 15 years, and without any fertilisation, it is reduced by approximately 30 to 40%. Poplar and willow (SRC) show a contrary trend. Only within the first few years they need some N fertiliser. The poplar clone Japan 105 guarantees high, secure yields of about 10 tDM/(ha y) even without fertiliser.

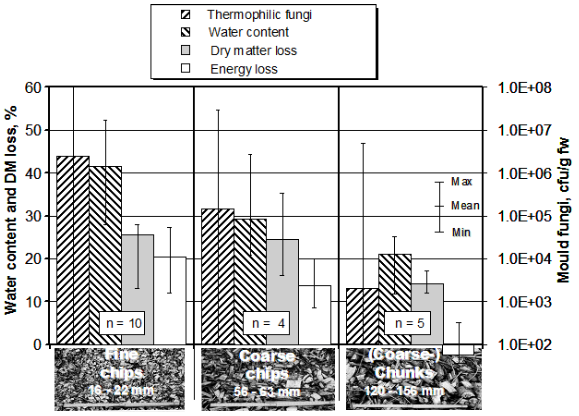

Figure 6. Influence of chopping length on wood chip storage

From the environmental and the energetic point of view, the application of 150 kg N/ha is generally inefficient. However, sustainable high energy yields are realised by applying 75 kg N/ha and in some cases (SRC) even less. With the exception of topinambur haulm and trees with undersown crops, the net energy gains, achieved with reduced nitrogen fertilisation, range between 122 and 167 GJ/(ha y), corresponding to 2.9 to 4.0 tOE (tonnes oil equivalent) per hectare and year. At the unfertilised block poplars reach approximately 172 GJ/(ha y) (4.1 tOE/(ha y)).

In addition to their high energy yield and their low demand for fertilisers and pesticides, SRC provide a set of further advantages. With mean contents of 0.7 % nitrogen, 0.06 % sulphur, and 0.01 % chlorine, they belong to those energy crop species, which cause the lowest environmentally harmful emissions during combustion and gasification. Furthermore they cause less climate effective nitrous oxide emissions during cultivation. Non-fertilised SRC fields emit only 15 to 30% of the N_2O of conventionally fertilised cereals.

Labour-management-related and economic advantages of SRC are the harvest time in winter, the free choice of the harvest intervals between 2 and 20 years. The relevant advantage, however, is that wood is a fuel for which proven combustion technologies with minimised emission rates are already available on the market.

Regarding the technology for the production chain, there is a need for small, lightweight, cost efficient SRC cutting chippers mountable on conventional tractors which are able to harvest e.g. up to 5 years old poplars and which can also be used on difficult soils, on small fields and in agroforestry systems. In that connection, the problems of storage of SRC chips, mainly caused by the chip size, should be solved too. The development of such a machine is an interesting challenge for agricultural engineering research.

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