SUSTAINABLE AND EFFICIENT ENERGY PRODUCTION ON FARMLAND

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Purpose of the Work

Biomass could cover a relevant share of the energy consumption worldwide. On the one hand there is politically and environmentally caused demand of bioenergy - by more than 8 % up to 2010 in the European Community - and on the other hand there is surplus of arable land growing with the entry of East European Countries into the Community. This farmland could to be used for the production of energy by the cultivation of energy crops [1]. These crops, cultivated on set-aside land, could substitute nearly 3 % of the primary energy in Germany and raise the income of farmers. However, the substitution of fossil fuels by plants requires the selection of plant species with high yields and ecological compatibility and energetic efficiency

Approach

In order to select such favourable plant species an experimental field was established Northwest of Potsdam on a relatively poor sandy 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 applied. 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 [2] [3].

Results

Yields

On the intensively fertilised blocks (A), hemp with 11.2 t_{DM}/ha, as well as cocksfoot, winter rye, and winter triticale with 8.4 to 8.9 t_{DM}/ha achieve the highest whole-crop yields. The originally promising topinambur haulm (Jerusalem artichoke) shows the lowest yield of all crops. In relation to a nitrogen application of 150 kg N/ha (block A), 8-year average yields decrease by only 6.9 % at 75 kg N/ha (blocks B and C), and they do not show a time-dependent tendency. This means that the relevant plant species can guarantee relatively high yields at the present location even if nitrogen supply is reduced for several years. Complete omission of fertilisation (block D) leads to a continuous yield reduction of 20 to 60 % after 8 years (Tab.1).

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 depressions. Since weeds are usually harvested with the energy plants, yield losses in comparison with a weed-free culture are insignificant [4].

Table 1: Mean dry matter production of the investigated energy plants from 1994 to 2003

Plant species	Dry matter yield (t/ha y) on the block			
	A 150 kg N/ha	B 75 kg N/ha	C 75 kg N/ha	D 0 kg N/ha
Cocksfoot grass	8.0	7.2	7.3	5.4
Willow*,Salix 21	7.6	6.4	6.9	6.0
Poplar*, Japan 105	7.0	6.9	7.4	6.7
Poplar, Japan 105	9.5	9.0	9.0	9.5
Poplar*, NE 42	5,4	6.5	6.9	6.9
Perennial rye	8.5	8.0	7.4	6.1
Topinambur	4.2	4.1	3.9	3.3
Hemp	11.2	10.5	10.0	8.9
Winter rye	8.5	8.1	7.6	6.6
Winter triticale	8.4	8.1	8.1	6.2

* with undersown grass

In poplars, the influence of fertilising on the yield is far less pronounced than in willows or even grain crops. Except for the poplar variety NE 42, which has an extremely high mortality rate, zero fertilisation (block D) causes poplar yield to diminish by 7 % over an 8 year average with undersown grass and, by only 3 %, without it as compared with intensive fertilisation (block A).

Macro and micro nutrients

The environmental relevance of plant nutrients results not only from the ecological effects of the fertilisers on the plant and the soil but also from the emissions during combustion and cultivation. In this connection nitrogen must be particularly emphasised.

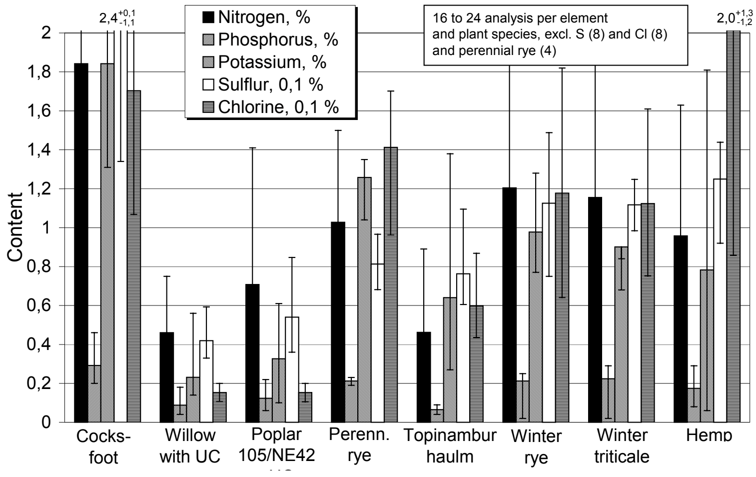

Fig. 1 Contents of emissions of relevant nutrients in energy crops

The nitrogen contents (N_t) of the different plant species exhibit an extraordinary range of variation. Cocksfoot, grain, and hemp reach the highest average N_t contents (0.9 to 1.9 %). With 0.4 to 0.7 %, the contents of trees and topinambur haulm are significantly lower (Fig. 2). Depending on the plant species, the application of 150-kg N/ha causes an average increase in the N_t content of 0.1 to 0.3 % [3]. This leads to an increase of nitrous oxide emissions (NO_x) of 10 to 50 mg/m³ during combustion [7], which is significant compared with legal limits in the range from 250 to 400 mg/m³.

The contents of sulphur (S) and chlorine (Cl) are within the range of the values given in the literature [7] [8] [9] [10]. 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 (Fig. 1).

During combustion, the sulphur contained 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.

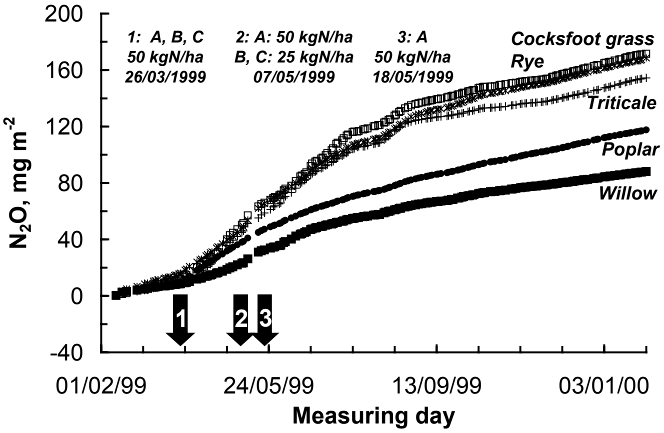

Fig. 2 Accumulated soil emissions of nitrous oxide during cultivation of energy crops

As shown by gas measurements, carried out on the experimental field over several years, the application of 150 kg N/ha causes an additional quantity of up to 100 mg/m^2 of nitrous oxide (N_2O) per year to be emitted from the soil [6]. And there is also a significant influence of the plant species. Poplar and willow cause less N_2O emissions than grass and cereals (Fig. 2). The total emission of climate-effective gases during production and utilisation of solid biofuels can be reduced up to 10 % by reducing N fertilisation and selecting appropriate crops.

Heavy metals

Among the six heavy metals analysed in the soil and the plants, especially those are interesting whose accumulation is caused by energyrelated input and/or input from fertilisers and whose emissions are legally limited, i.e. cadmium, lead, copper, and zinc.

Cadmium (Cd), which is produced during smelting and the combustion of fossil raw materials and which is contained in superphosphate as well as some kinds of biomass ashes, is phytotoxic and may lead to functional kidney disorder and bone damage along with other detrimental effects [7] [11]. With contents of 1.2 to 2.2 mg per kg of dry mass, cadmium is preferably absorbed by poplars and willows. Whole-crop grain such as rye and triticale, which are conventionally used as food and foodstuff, have significantly lower contents of 0.03 to 0.08 mg/kg_{DM}.

Motor-vehicle traffic is the main source of anthropogenic lead (Pb) emissions. In humans, intoxication causes damage to the nervous system and the kidneys along with other harmful effects [11]. Lead is preferably absorbed by cocksfoot. Its content reaches values of more than 5 mg/kg, while the average lead content of the other plant species remain below the detection limit of 1 mg/kg. Like the previously mentioned metals, zinc (Zn) and copper (Cu) are released during smelting. Additionally, zinc can be found in abraded tire material, engine oil, and the smoke gas of coal combustion plants. Copper is contained in electric power lines and water pipes. Characteristic of both metals is that they are essential and toxic. However, an increased input does not constitute a severe health risk to humans [11]. The mean zinc content of the plants ranges between 15 mg/kg_{DM} (rye) and 135 mg/kg_{DM} (cocksfoot). The content of copper in the plants varies between 2.6 mg/kg_{DM} (poplar) and 22.6 mg/kg_{DM} (cocksfoot).

Energetic efficiency

For the determination of the energetic efficiency and the energy gain of the production and utilisation of energy plants, energy requirements and –yields must be established and compared.

The cumulated energy demand is determined using a method which takes all direct and indirect primary energy requirements into account [5]. 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.

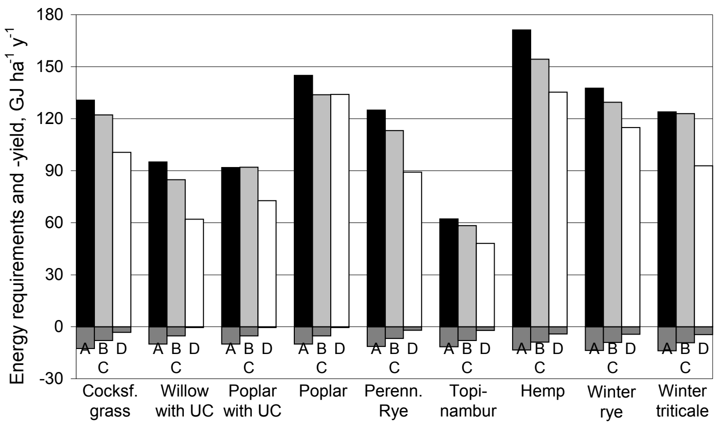

Fig. 3 Demand and yield of energy for the production of energy crops

Independent of the fertilisation variant, the annual (net-) energy gain, which results from the difference of energy demand and -yield, ranges between 97 and 178 GJ/(ha y) for grain, cocksfoot, and hemp. With 161 to 172 GJ/(ha y), the poplar variety Japan 105 without undersown crops also achieves rather high energy gains. With the exception of poplar, 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 (Fig. 3).

Conclusions

The 8 years cultivation of various energy plants on sandy soil shows that fertiliser application can be reduced significantly and that pesticides can generally be dispensed with. On high fertilisation level, the mean yields of above-ground biomass range between 4.2 and 11.2 t_{DM}/ha. Hemp, poplar and whole crop grain achieve the highest yields, while topinambur haulm as well as all field wood with undersown crops have the lowest.

If fertiliser application is reduced from 150 to 75 kg N/ha, the approximate average yield diminishes by only 7 %. Without any fertilisation, it drops continuously and, after 8 years, it reaches ca. 40 to 80 % of the yield achieved with 150 kg N/ha. An exception is poplar. The variety Japan 105 guarantees high, secure yields of nearly 10-tDM/ha y even without fertilising. In this case, however, undersown grass must be dispensed with, even if the large poplar leaves suppress the grass after some years.

The application of 150-kg N/ha is generally energetically inefficient. Sustainable high energy yields are also realised by applying 75 kg N/ha and in some cases 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 2.9 to 4.0 TOE (Tonnes Oil Equivalent) per hectare and per year. Without fertilisation, 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, poplars also have a series of further advantages. With mean contents of ≤ 0.7 % nitrogen, ≤ 0.06 % sulphur, and ≤ 0.01 % chlorine, they belong to those energy plant species, which cause the lowest emissions during combustion, and they emit not much environmentally harmful nitrous oxide during cultivation. Like willows, they have an extraordinarily high accumulative capacity for heavy metals, especially cadmium. Due to the upgrading of the heavy metals in the filter ashes, a sustainable contribution towards the decontamination of the soil can be made even if the grate ashes are recycled as fertiliser.

Labour-management-related and economic advantages of field wood are the harvest time in winter, the free choice of the harvest intervals between 2 and 10 years, and the possibility of subsidised cultivation on set-aside land. The decisive advantage, however, is that wood is a fuel for which proven combustion technologies with minimised emission rates are already available.

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