# ENERGY FROM FARMLAND - EFFICIENT AND ENVIRONMENTALLY FRIENDLY

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## INTRODUCTION

In the medium term, energy plants cultivated on fields, which are not needed for food production, could provide approximately one third of the energy generated from biomass. This would correspond to more than 3% of the demand for primary energy in Germany. Even though energy plants are renewable energy sources, they will only have a chance in the long run if their cultivation and utilisation do not cause any impermissible pollution and if the net energy gain per area unit is sufficiently high.

The total of approximately 60 preferable species of energy plants differ with regard to yield, habit, susceptibility to pathogens, habitat adaptation, technology, harvest moisture, fertiliser- and plant-protection product requirements, etc. [1]. When choosing suitable species, especially ecological and energetic aspects of production and utilisation must be taken into account, in addition to agronomic and technological characteristics.

Therefore, the ecological compatibility and energetic efficiency of the cultivation of different energy plant species suitable for combustion was determined in an integrated project under practical conditions on sandy soil.

## MATERIAL AND METHOD

The experimental field is situated Northwest of Potsdam. It 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 $ha^{-1}$. On blocks B and C, wood- and straw ashes as well as 75 kg N $ha^{-1}$ each are applied. Block D is not fertilised. On the entire area, no plant protection products are applied. As fertilisers, 540 or 270 kg $ha^{-1}$ of calcium-ammonium nitrate and 520 kg $ha^{-1}$ of potash-magnesia/ super-phosphate mixture, as well as 660 kg $ha^{-1}$ of coarse ashes each from a wood- and a straw combustion plant are used.

The index of land quality ranges between 28 and 34. In the upper horizons up to a depth of 60 cm, weakly humous, slightly loamy sand and underneath sandy loam of diluvian origin are predominant. The ground water table is about 8 m. At the beginning of the trial, the contents of humus and organically bound carbon averaged 15.5 g $kg^{-1}$ and 9.0 g $kg^{-1}$. The mean pH-value was 5.7. The experimental field is situated in a climate region, which is characterised by a relatively balanced climate. Nonetheless, significant differences in yearly average temperature and precipitation occurred during the trial period between 1994 and 2001. The average annual mean temperature was 9.4 °C. The sum of precipitation amounted to 509 mm per year [2] [3].

## YIELD

On the intensively fertilised blocks (A), hemp with 11.2 $t_{DM}$ $ha^{-1}$, as well as cocksfoot, winter rye, and winter triticale with 8.4 to 8.9 $t_{DM}$ $ha^{-1}$ achieve the highest whole-crop yields. As expected, the yield of perennial rye drops from 10.2 to 5.9 $t_{DM}$ $ha^{-1}$ within 3 years. The originally promising topinambur haulm (Jerusalem artichoke) shows the lowest yield of all crops. In relation to a nitrogen application of 150 kg N $ha^{-1}$ (block A), 8-year average yields decrease by only 6.9% at 75 kg N $ha^{-1}$ (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 10 years (Fig. 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].

The measured yields of short rotation coppice (SRC) or so-called field wood exhibit an extraordinary range of variation and are determined less by fertiliser application than by the undersown crop and the age of the trees. The undersown crop (UC), a modest grass, proves to be a significant water- and nutrient competitor, which causes the yield of the fast growing balsam poplar hybrid Japan 105 to diminish by 10 to 65% within the first 4 years depending on the fertilising regime and the rotation interval.

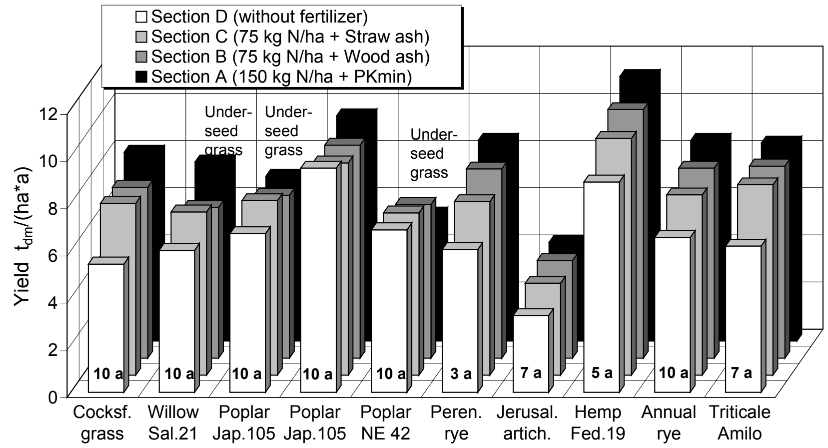

**Fig. 1.** Average yield of the investigated energy crops (1994 - 2003)

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, the zero fertilisation (block D) causes poplar yield to diminish by 5% over a 10 year average with undersown grass and, by only 1%, without it as compared with intensive fertilisation (block A). The corresponding yield reduction of willow is 21%.

## ENVIRONMENTALLY RELEVANT SUBSTANCES

### 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.

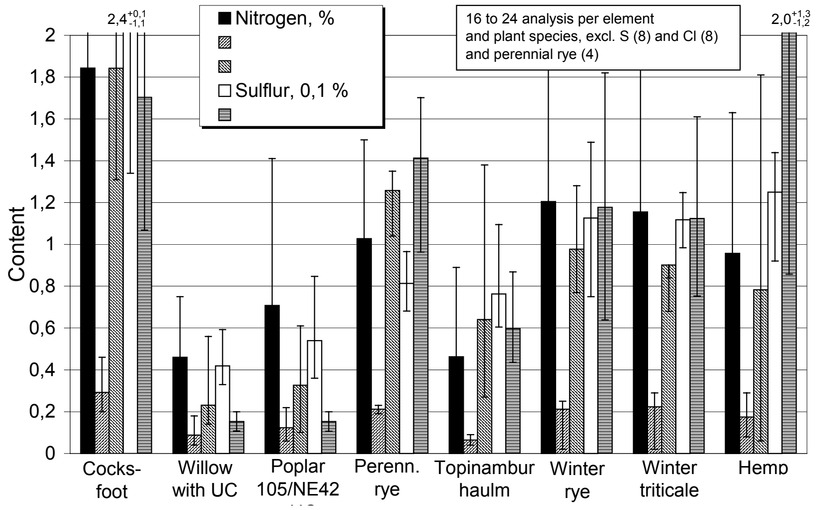

**Fig. 2.** Contents of emissions of relevant nutrients in energy crops

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 $ha^{-1}$ 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 $m^{-3}$ during combustion [7], which is significant compared with legal limits in the range from 250 to 400 mg $m^{-3}$.

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. 2).

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.

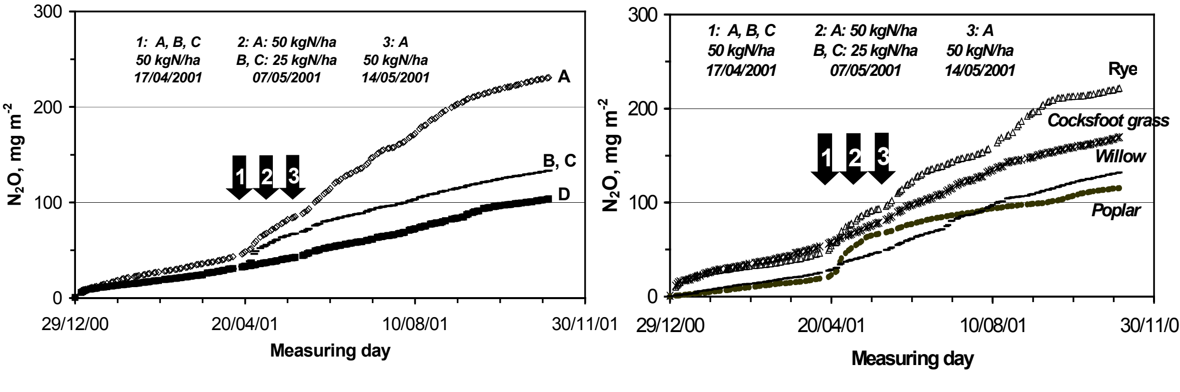

**Fig. 3.** Accumulated soil emissions of nitrous oxide during cultivation of energy crops
left: depending on N-application rate right: depending on plant species

As shown by gas measurements, carried out on the experimental field over several years, the application of 150 kg N $ha^{-1}$ causes an additional quantity of more than 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. 3). The total emission of climate-effective gases during production and utilisation of solid biofuels can be reduced up to 30% 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 energy-related 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 $kg^{-1}{}_{DM}$.

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 $kg^{-1}$, while the average lead content of the other plant species remain below the detection limit of 1 mg $kg^{-1}$. 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 $kg^{-1}{}_{DM}$ (rye) and 135 mg $kg^{-1}{}_{DM}$ (cocksfoot). The content of copper in the plants varies between 2.6 mg $kg^{-1}{}_{DM}$ (poplar) and 22.6 mg $kg^{-1}{}_{DM}$ (cocksfoot) (Fig. 4).

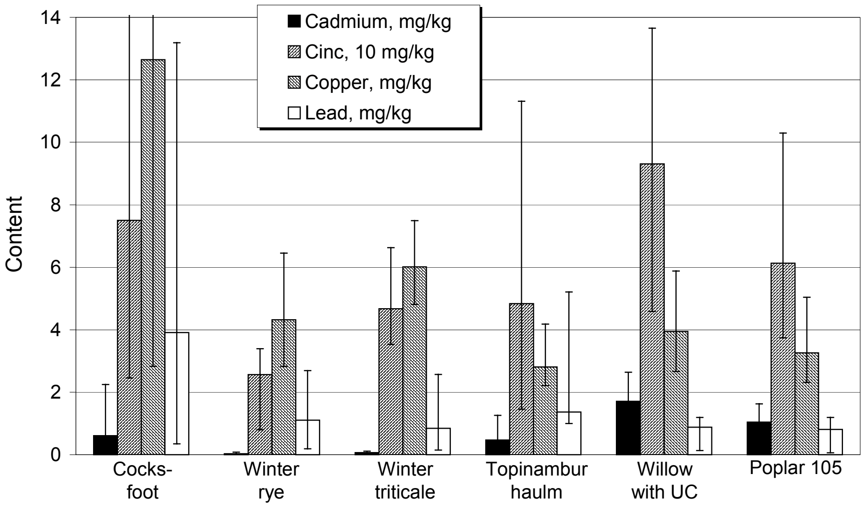

**Fig. 4.** Environmentally relevant heavy metals

## 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].

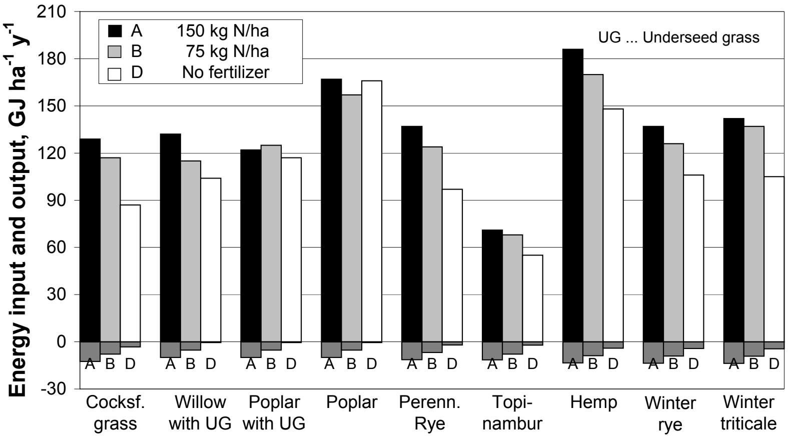

**Fig. 5.** Demand and yield of energy for the production of energy crops

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, which results from the difference of energy demand and -yield, ranges between 95 and 170 GJ $ha^{-1}$ $y^{-1}$ for grain, cocksfoot, and hemp. With 160 to 175 GJ $ha^{-1}$ $y^{-1}$, 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. 5).

## CONCLUSIONS

On sandy soils appropriate energy crops get yields of up to 11 tons dry matter per hectare and year. Hemp, poplar and whole crop grain achieve the highest yields, while topinambur haulm as well as all field wood (SRC) with undersown crops have the lowest. The 10 years cultivation shows that fertiliser application can be reduced significantly and that pesticides can generally be dispensed with.

If fertiliser application is reduced from 150 to 75 kg N $ha^{-1}$, the approximate average yield diminishes by only 8%. Without any fertilisation, it drops continuously and, after 10 years, it reaches nearly 40 to 80% of the yield achieved with 150 kg N $ha^{-1}$. An exception is poplar. The variety Japan 105 guarantees high, secure yields of nearly 10 $t_{DM}$ $ha^{-1}$ $y^{-1}$, even without fertilising. However, undersown grass must be dispensed with, although the large poplar leaves suppress the grass after 4 to 6 years.

The application of 150 kg N $ha^{-1}$ is generally energetically inefficient. Sustainable high energy yields are also realised by applying 75 kg N $ha^{-1}$ 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 110 and 160 GJ $ha^{-1}$ $y^{-1}$, corresponding 2.9 to 4.3 TOE (Tons Oil Equivalent) per hectare and per year. Without fertilisation, poplars reach approximately 172 GJ $ha^{-1}$ $y^{-1}$ (4.1 TOE $ha^{-1}$ $y^{-1}$).

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 less environmentally harmful nitrous oxide during cultivation than haulm type energy crops. Furthermore poplars and willows have an extraordinarily high accumulative capacity for 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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