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HIGH-GRADE FUEL FROM ENERGY WILLOW FARMING

ABSTRACT. Energy willow farming was developed in Finland and in Sweden in the mid seventies. Notable energy yields have been collected by selecting, breeding and raising fast growing coppicing willow crops. At high latitudes with a severe wintertime, a one year rotation is used; in central and southern parts of the Nordic countries a rotation period of 2-5 years seems to be the most productive. An energy system is described in which methanol is converted from wood produced from wood produced on willow plantations. With moderate energy inputs and willow yield levels the system works as an energy amplifier in terms of high-grade fuel. Net energy yields of 3000 - 4000 kg/ha/year methanol could be achieved with present day technology. The sensitivity analysis of the system shows the importance of high-yielding willow clones in concentrating future R & D efforts.

INTRODUCTION

Energy farming is a discipline of cultivated plants and husbandry in which the solar radiation is collected and converted into biotic energy of the phytomass. The aim is to produce high energy yields by selecting, breeding and raising fast growing crops.

Promising results in northern energy farming have been achieved with the use of selected willow clones. Energy willow farming was developed in Finland and in Sweden in the mid-seventies. It has its modern origin in the concept of mini-rotation forestry (1). Initially the aim was merely to produce more raw material for the expanding wood industry, using methods as intensive as those used in agriculture.

The first field experiments were established in 1973. Promising results were obtained at once. A Danish willow clone, Salix cv. "Aquatica" produced in the latitude of the arctic circle a dry matter (DM) yield of about 10 tons/ha already during the first summer (2).

More willow species have been screened in subsequent experiments. The annual yields have been maintained at their high level, between 10 and 20 tons/ha, in energy equivivalents up to 350 gigajoules (GJ) per hectare (3). The largest dry matter yield so far reported (4) has been 32 tons/ha, which includes the harvested stemwood only.

ASPECTS OF WILLOW HUSBANDRY

Energy willow farming can be carried out in two ways. If the clones used are completely frost resistant they can be grown like any other deciduous crop; the rotation period will vary between 2-5 years. If the shoots do not survive the winter, but the stumps and roots do, a one year rotation period is used.

So far it is not yet clear which one of the two practices will give the highest yields. With a rotation period of a number of years, dormancy reduces the level of photosynthesis in the autumn, but in early summer the foliage develops rapidly on the already existing shoots. With one year rotation the growth early in the growing season is slower. However, as there is no need for winterhardening of the shoots, the leaves continue to fix carbon at a high rate right up until the onset of the autumn frosts. The active period of willow under one year rotation lasts until October. The period is about one month longer than that for birch.

In the central and southern parts of the Nordic countries 2-3 year rotation will probably give the highest yields. Moreover, perennial crops seem to produce more energy-rich shoots that also are structurally better suited to the cutting devices of future harvesting machines (5).

One advantage of energy willow is that it can be clonally propagated. The crop is established using cuttings. After the first harvest the willow will coppice 5-20 shoots per cutting, depending on genetic differencies between the clones.

The shoot density, which is greatly determined by the coppicing ability, has a clear effect on the yield. The main rule holds that the larger the number of vigorous shoots, the greater the yield will be (6). As a practical compromise, we aim at a shoot number of 30 per square meter in one year crops. With this density full coverage is established within one month in the spring.

Row cultivation can be carried out in such a way that ordinary tractors can later on operate without damaging the stools. Planting as well as harvesting can be mechanised at little cost.

Wood ash plays an important role in the recirculation of nutrients. In actual fact, if the energy crop is burned in a heating plant, most of the nutrients can be returned to the plantation in the ash. Nitrogen escapes to the atmosphere; minor potassium losses have also to be compensated for.

Nitrogen fertilizer is fixed from atmospheric reserves using a certain amount of energy. It has been estimated that the whole chain of nitrogen from the atmosphere through the factory to the field, requires an energy input of 77.0 MJ/kg nitrogen as fertilizer (7). About 100 kg/ha is annually needed to substitute the nitrogen removal (8). At this level an energy input of 7.7 GJ/ha thus maintains the cycling of nitrogen between the atmosphere and the energy plantation.

Since willow plantations are still only on an experimental scale, the other inputs needed for the estimate can be obtained from information concerning similar husbandry with other crops. The total energy input in the energy willow may well be of the order 20 GJ/ha/year (9). This level corresponds for instance with that for the intensive <u>Populus</u> "tristis" husbandry of Zavitkovski (7, without irrigation). With such an input a <u>Salix</u> cv. "Aquatica" plantation is able to produce an annual stem yield of 12 tons/ha (DM)(8). In gross energy yield, it equals 197 GJ/ha/year (3).

HIGH-GRADE FUEL FROM ENERGY WILLOW

The energy willow system can work as an energy amplifier in terms of high-grade fuel. We choose methanol as an example since present-day technology converts methanol from wood more efficiently than the other possibility ethanol. Our calculation is based on a recent plan to convert Finnish peat fuel into methanol (10). With minor adjustments the proposed plant could also accept forms of phytomass other than peat as feedstock. The approach and notations are from Weisz and Marshall (11).

The agricultural input required to produce the high-grade fuel is denoted by A and the gross energy yield by Y_o. The input-output ratio f expresses the efficiency of the crop and of the type of husbandry practised ($f = A/Y_o$). In the example, $A = 20.0$ GJ, $Y_o = 197$ GJ, and $f = 0.102$. In other words, the energy input is 10 percent of the crop energy output.

Methanol can be produced by the partial combustion of the willow phytomass by oxygen and steam. The conversion plant is self-sufficient as regards its energy requirements. Part of the incoming willow yield is burned in a counter-pressure power plant. The electricity required in the conversion process is thus produced by the plant itself.

The energy yield in high-grade fuel (methanol) is denoted by G, and the conversion efficiency from biomass Y_0 to fuel by n, thus $G = nY_0$. It is calculated that the output of the methanol plant would be 359 grams methanol for every kilogram DM of input. Thus the 12 000 kg of willow is converted into 4310 kg methanol. Using the heat of combustion value 20.1 MJ/kg, the methanol output corresponds to G = 86.6 GJ. The conversion efficiency n = 0.440.

A capacity of 1000 tons/day methanol has been considered suitable for the factory. Such a capacity could provide a mixture of 15 per cent methanol for all the one million cars in Finland. With a yield level of 12 tons/ha DM the area needed to satisfy the raw material demand of the factory would be about 111 000 ha. This is five per cent of the total area under agricultural crops, and 0.6 per cent of the forested land in Finland.

Sensitivity of the net energy yield

The net productivity of N of high-grade fuel from the total system is:

$$N = G - A = nY_0 - fY_0 = Y_0(n - f) \qquad (1)$$

In our basic case N = 66.6 GJ/ha. The net energy yield depends on three efficiency measures: Y_0 describes the efficiency of the clone (genetic material) selected for cultivation, n is the conversion efficiency in man-made methanol factory, whereas f measures the conversion efficiency from agricultural input to biomass built by the solar energy. All of these components can apparently be improved.

The net energy yield is directly proportional to the gross energy yield Y_0. In southern Sweden a yield level of 18 tons/ha/year (DM) has been achieved on areas large enough to serve as a basis for generalizations (5). Assuming a rise in the yield to this level will raise the net energy yield by a factor 1.5 up to 100 GJ/ha.

In order to maintain positive balance in the net energy yield the agricultural input-output ratio f may vary between zero and n. In practice we could improve our husbandry so that f would maybe diminish from 0.102 down to 0.050. However, this would raise the net energy yield from N = 66.6 only to N = 69.0 GJ/ha.

The fuel conversion efficiency may vary between 1.0 and f. Thermochemical processes developed in Sweden for the conversion of wood into methanol indicate outputs with an energy efficiency of over 50 per cent (12). Let us assume a rise from n = 0.440 up to n = 0.500. This would raise the net energy yield into N = 78.4 GJ.

CONCLUSIONS

There is a common objective that man should become less dependant on nonrenewable energy sources. There are plenty of alternatives. The proper selection of the most promising strategies could be helpful in concentrating future R & D efforts. Although our knowledge about the possibilities of renewable energy is still insufficient, it is becoming possible to separate out "the promising" and "the less promising" strategies (13).

In our view energy plantations belong to the group of promising strategies. In this paper we have shown that it is possible to achieve a highly positive energy balance in the energy willow system starting from the agricultural input and ending in a liquid fuel, methanol.

Our present society waits for alternative fuels which must be processed to some extent. Today, in fact, the mankind is in love with liquid fuel. Choosing methanol as an example of a possible alternative of oil, also satisfies the requirement of high-grading in the theoretical calculations. We now can compare the energy inputs and outputs in our energy willow system with the same measure.

The energy willow - methanol system is most sensitive to the gross biomass yield. The net energy return is rapidly improved if more and more high-yielding clones could be developed. Since our experimental willows actually are still wild plants the modern plant breeding has promising possibilities.

The agricultural input-output ratio has an amazingly faint effect on the net energy yield. This calls for more intensive husbandry. We should not be afraid of high densities, fertilization etc., since it is the net energy that counts.

Today the production of methanol is still, without doubt, cheaper from natural gas or coal instead of biomass. In the longer run, however, gas and coal can only be temporary solutions because of their nature of nonrenewability. Moreover, the countries with no oil, gas and coal resources are now becoming more and more interested in the possibilities of biotic solar energy. The sun is safe and democratic: without restrictions and without delays it shines to all countries in the west as well as in the east, and in the industrialized countries as well as in the developing world.

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