SVERIGES LANTBRUKSUNIVERSITET

ENERGY ANALYSIS OF REED CANARY GRASS FOR SOLID FUEL AND LEY FOR BIOGAS

Edmundo Hetz
Ulf Sonesson

Institutionen för lantbruksteknik

Swedish University of Agricultural Sciences
Department of Agricultural Engineering

Rapport 175
Report
Uppsala 1993
ISSN 0283-0086
ISRN SLU-LT-R--175--SE

DOKUMENTDATABLAD för rapportering till SLU:s lantbruksdatabas LANTDOK, Svensk lantbruksbibliografi och AGRIS (FAO:s lantbruksdatabas)

Institution/motsvarande Inst f lantbruksteknik	Dokumenttyp Rapport	
	Utgivningsår 1993	Målgrupp F, R

Författare/upphov

Edmundo Hetz
Ulf Sonesson

Dokumentets titel

Energy Analysis of Reed Canary Grass for Solid Fuel and Ley for Biogas

Ämnesord (svenska och /eller engelska)

Bioenergy, Biofuel, Biogas, Biomass Utilization, Energy, Energy analysis, Energy balances, Energy grass, Energy systems analysis, Reed canary grass

Projektnamn (endast SLU-projekt)

Serie-/tidskriftstitel och volym/nr Sveriges lantbruksuniversitet, Inst f lantbruksteknik Rapportserien, Rapport 175	ISBN/ISRN SLU-LT-R--175-SE
	ISSN 0283-0086

Språk	Smf-språk	Omfång	Antal ref.
Engelska	Engelska	14 s.	21

Postadress	Besöksadress	Telefonnummer	Telefax
SVERIGES LANTBRUKSUNIVERSITET Ultunabiblioteket, Förvärvsavdelningen/LANTDOK Box 7071 S- 750 07 UPPSALA Sweden	Centrala Ultuna 22 Uppsala	018-67 10 00 vx 018-671103	018-3010 06

PREFACE

Edmundo J Hetz is a Professor at the Faculty of Agricultural Engineering of the University of Conception, Chile. He spent one month as a guest researcher at the Department of Agricultural Engineering of the Swedish University of Agricultural Sciences. Funds for this exploratory mission were sustained by the agreement SAREC/CONICYT Sweden/Chile.
Ulf Sonesson is a researcher at the Department of Agricultural Engineering of the University of Agricultural Sciences.
This report is part of the NUTEK project 146310-2, Energy Systems Analysis in Forestry and Agriculture.

SUMMARY

Considering the large interest there is in Sweden for alternative use of land set aside and the production of renewable fuels this study was carried out to evaluate the suitability of reed canary grass (Phalaris arundinacea) and a ley of red clover (Trifolium pratense) and timothy grass (Phleum pratense) as energy crops.

The typical production systems for each crop was established, a set of assumptions were also agreed upon and all inputs and outputs were identified, quantified and expressed in MJ/ha.

Reed canary grass was to last ten years and the harvest is done in the spring. A four year rotation was established for the ley with barley as a nurse crop in the first year. As outputs of the ley system the following were considered: barley grain, barley straw, biogas and nitrogen in the digesters residues which were assumed spread on the field.

As parameters of efficiency Net Energy Gain (N.E.G) and the output/input ratio were calculated.

The main results showed a N.E.G of 56 417 MJ/ha and year and an output/input ratio of 7.4 for the reed canary grass; biogas production from the ley gave a N.E.G of 53 000 MJ/ha and year and an output/input ratio of 2.9.

TABLE OF CONTENT

INTRODUCTION

The Swedish agriculture has a problem with overproduction of food. Because the prices at the world market are so low these surpluses are sold with great losses. These losses are very expensive both to the farmers and the state. There are different opinions of how many hectares of surplus land there are, but a figure of 500 000 hectares in total would be a good estimate.
To solve this economical problem the Swedish government in 1990 started a five year program to change the production from food to something else. The farmers received subsidies for not producing food on their land and show that they had started producing something else. At the same time the custom taxes for imported food where lowered and the prices of grain, meat and milk decreased.
This program was meant to make possible the investment in cropping systems that take some years before it creates an income.
Some farmland was planted with trees, mainly spruce but also some birch and oak. This planting of trees is a matter of discussion. In a country like Sweden where the open land is very rare, its not popular to plant spruce on the still remaining farmland, especially not since this planting is done mainly on fields with low yields, and difficult to cultivate, i.e. often small fields surrounded by forest.
Another problem with wood planting is that the farmer can not continue being a farmer, the spruce will not give him any income for the first thirty years. That means that he has to take another job and perhaps even move away from his farm.

Because these disadvantages many farmers do not want to plant spruces on their land. But what are the alternatives?
At the same time that Sweden has this problem with set aside land, it is also highly depending on imported fossil fuels for energy purposes. Since the first oil crisis of 1973 Sweden has managed to diminish its use of fossil fuel from 75% of the energy produced in 1970 to 50% in 1990, (NUTEK, 1992) but it is still a big problem. This problem is not only economical but also environmental. The burning of fossil fuels increases the greenhouse effect by discharging carbon dioxide to the atmosphere. Also the acidification by discharging sulphur is a major problem, especially in Sweden with soils very sensitive to acid rains.
When biofuels are used, i.e. straw, wood and so on, these problems almost vanish. So, these two problems seem to have at least in some sense the same solution. By growing crops only for energy purposes the farmers get good use for their land and the environment is not damaged by burning fossil fuels.

These energy crops are considered by most experts and farmers the only alternative on set aside land that can take up a significant area. Up till now the energy crops have not become very common, due to low prices of energy in Sweden, and also because the technology for these cropping systems has not been effective enough. Now, when the authorities subsidy alternative crops and the researchers have come up with new solutions for energy cultivation, the time perhaps has come to change from fossil- to biofuels on a larger scale.

One aspect that must be evaluated concerning biofuels is their efficiency in catching solar energy and convert it into biomass, i.e. collect energy from the sun. This has not been done very thoroughly in the past. There have been more or less accurate estimations, especially concerning the energy cost for using machinery in the production system. This evaluation is important to make the right decisions about which crops are to be preferred in any specific situation.

The crops that are most promising are:

-Energy forest of willow (Salix ssp), for heat production or producing ethanol as a fuel for engines.

-Rape seed for producing oil as a fuel for diesel engines

-Winter wheat for producing ethanol as a fuel for engines, or for heat production.

-Energy grasses for burning or biogas production.

Sonesson (1993) concluded that the output/input energy ratios for some of these alternatives were as follows: Salix for heat production 19.3:1; salix for ethanol production 1.82:1; rape seed oil 3.08:1; rape methyl ester 2.74:1; and winter wheat for ethanol production 1.25:1 and for heat production 3.79:1.

Definitions

Reed canary grass (Phalaris arundinacea) is grown as a solid fuel, it is either burnt as straw or converted into powder before burning. There is about 4 000 hectares of this crop in Sweden in 1992. The grass is harvested in the spring because that is the best way to get it dry enough for safe storing.

Ley, consisting of red clover (Trifolium pratense) and timothy grass (phleum pratense) for biogas production is not grown comercially in Sweden today, but there is research going on in this field. Biogas is produced by digesting organic matter such as carbon hydrates, proteins and fats in an anaerobic environment. The organic matter is decomposed by hydrolysis to simple organic combinations, which then are decomposed further to methane and carbon dioxide by bacteria.

Objective

The objective of this study was to evaluate the suitability of reed canary grass (Phalaris arundinacea) and a ley of clover (Trifolium pratense) and timothy grass (Phleum pratense) as energy crops.

METHODOLOGY

Production systems

The typical production systems for reed canary grass and ley (red clover and timothy grass) were established through a series of meetings with experts from the Institute of Agricultural Engineering in Uppsala (Messrs M. Dalemo, G.Hadders and L. Thyselius).

Reed canary grass (Phalaris arundinacea)

The production system established for reed canary grass, lasting for 10 years, included the following operations.
-Ploughing.
-Harrowing three times.
-Fertiliser spreading (NPK) two times.
-Seeding.
-Soil compaction by rollers.
-Cutting/conditioning.
-Baling.
-Transport to farm and heating plant.
-Fertiliser spreading (N) eight times.

Clover and timothy grass ley (Trifolium pratense and Phleum pratense)

The production system established for ley, lasting four years, included a nurse crop of barley in the first year and two cuttings per year the next three years; the following operations were assumed in year one:
-Ploughing.
-Harrowing three times.
-Seeding of barley combined with fertilising.
-Soil compaction by rollers.
-Seeding of grass.

-Harvest, transport, drying of barley grain.
-Baling and transport of barley straw.
In years two, three and four the following operations were performed twice per year:
-Cutting/conditioning of ley.
-Chopping/baling.
-Transport of bales to biogas plant.
-Transport of digester residues to farm.
-Fertilising (done only once in year two).

Assumptions

The following main assumptions were established:
-The farms are situated in the Mälar valley.
-The distance field to farm is 1 km and farm to plant is 15 km (Stout, 1990).
-The field is 10 hectares.
-The reed canary grass yields 5 tonnes of dry matter per hectare (6 tonnes of grass) and harvests are carried out at springtime (Hadders, 1993).
-The biogas digester has 3000 m^3 of volume, covers 450 hectares of ley, and has a useful life of 20 years (Blomberg, 1993).
-The barley of year one yields 3.4 tonnes/ha of grain and 2.3 tonnes/ha of straw.
-Barley grain drying uses 423 MJ/tonne (Sonesson, 1993).
-The yield of the ley is 7.7 tonnes dry matter/ha and year in the two cuttings (SLU, 1989).
-Ten percent (10%) of the energy content of the biogas is used to maintain the 35°C the digester (or actually the bacteria that are doing the job) needs to work (Dalemo, 1993).
-Five percent (5%) of the energy content of the biogas is used for pumping and agitating in the biogas process (Dalemo, 1993).
-The methane yield of the ley is 300 l (1 bar, 20°C) per kg of volatile substance (dry matter minus ashes), this is the same as about 420 l of biogas (Thyselius, 1993).
-Labour and farm buildings were not accounted for (Fluck 1992).
-The system boundary for the reed canary grass is the store room of the heating plant and for the ley the biodigesters's valve outlet.

Identification and quantification of inputs and outputs

All inputs and outputs of the production systems were thoroughly identified and quantified in adequate units like l/ha, kg/ha. They were later expressed in units of energy per hectare using the equivalencies shown in Table 1. The tractor and

machine sizes used were the ones most common among Swedish farmers. Machine weights , standard useful life, and effective field capacity (h/ha) were used to calculate the energy cost of mechanised operations on a per hectare basis (Elinder and Falk 1983; NMTI 1987-1992; Bogballe, 1985; Gisebo, 1990; JF, 1985; Sundquist, 1993; Väderstad, 1985 and Överum, 1985).
As an example, let's consider ploughing: the plough weighs 852 kg, it has a useful life of 1000 h and an energy intensity of 109 MJ/kg; therefore, one hour of plough use, without tractor, costs: (852 kg*109 MJ/kg)/1000 h, which adds up to 92.9 MJ/h. If 2.2 h/ha are needed the plough per hectare costs 204 MJ/ha.
The numbers that appear in table 2 and 4 as kg/ha are calculated as follows: (2.2*852)/1000=1.87 kg/ha, for the plough.

Parameters of energy efficiency

The parameters used to calculate the energy efficiency of the systems were:
-Net Energy Gain=Energy output-Energy input, MJ/ha and year.
-Energy output/input ratio=Energy output/Energy input, presented as a number without units.

RESULTS AND DISCUSSION

Reed canary grass

Tables 2 and 3 show the energy utilisation and distribution in reed canary grass production.
The energy requirements added up to 8 833 MJ/ha, of whitch almost half (48.9%) corresponds to the nitrogen fertiliser; if diesel fuel and machinery are considered as one item they add up to about the same as the nitrogen fertiliser (47.6%). These results are similar to what other authors have found (Fluck 1992, Stout 1990, Sonesson 1993); this is explained by the very high energy intensity per unit of nitrogen fertiliser and diesel fuel.
However, it is expected that in a system with spring harvest the amount of nitrogen fertiliser can be significantly reduced without decreasing the yield (Hadders, 1993). This is due to the fact that during winter most of the nitrogen in the plant returnes to the soil, (Hadders, 1993).
On the other hand, the assumed yield (Hadders 1993) added up to 65 250 MJ/ha, corresponding to 5 tonnes of dry matter . This harvested yield can vary in the range from three to perhaps eight tonnes of dry matter per hectare.

The previous results yield a net energy gain, N.E.G, of 56 417 MJ/ha and year and an output/input ratio of 7.4; this output/input ratio is higher then the 5.5 ratio found out for hay in Sweden (FAO 1989). The same study show a N.E.G of approximately 130 000 MJ/ha and year. This is explained by a higher yield (9 tonnes/ha), a higher energy content (17.6 MJ/kg), and the excluding of the energy used in machinery manufacturing.

However, in economic terms ordinary hay making use very expensive energy inputs for the drying process and the whole production system becomes uneconomical due to the low prices of solid fuel (Hadders, 1989). On the other hand, spring harvested canary grass does not need to be artificially dried, therefore it has a better chance to become economically attractive.

The assumed yield of 5 tonnes DM per hectare is the average level of today. It is reasonable to believe that the average yield can be increased up to six tonnes DM per hectare, by reducing the losses during harvest operations (Hadders, 1993). The six tonnes yield increase the inputs with 576 MJ/ha and year, due to more energy needs for harvesting, transports and handling of the bales. The output will increase 13 000 MJ/ha, so the N.E.G will be 68 891 MJ/ha. The output/input ratio will be increased to 8.3.

From Table 3 it can be seen that bale handling and transportation is the most energy expensive operation, with 34.0% of the total, followed by baling with 33.8%. If cutting is added, these three operations account for 83.8% of the total. The explanation is that these operations have to be carried out every year.

Ley for production of biogas

Tables 4 and 5 show the energy utilisation and distribution in biogas production from ley. Total energy requirements amounted to about 28 000 MJ/ha, with diesel fuel and machinery as the biggest field items (54.9%), and digester warming and pumping as the biggest processing items (31,8%). In this case there is no nitrogen fertiliser input because of the clover in the ley; on the contrary there is 648 MJ/ha of nitrogen output, from the residues of the digester.

On the other hand total output added up to about 81 000 MJ/ha of which the most important was methane, with 73.2% of the total; the rest is barley grain and straw the first year accounting for 35.9%.

The net energy gain added up to about 53 000 MJ/ha and year with an output/input ratio of 2.89. These results should lead to an optimistic future towards growing ley as an energy crop. However a thorough economical study should be carried out before any conclusion can be drawn.

From Table 5 it can be seen that the most energy expensive operations were ley harvest and transportation, adding up to 48.2% of the total. Handling the digesters residues (liquids and solids) also accounted for significant energy cost, adding up to 24.6% of the total.

In conclusion this preliminary study showed that both crops, canary grass and ley, present a good alternative for land set aside, where these crops could be grown as a source of renewable energy.

REFERENCES

Bertilsson, G. 1992. Environmental consequenses of different farming systems using good agricultural practices. Hydro Supra AB. Landskrona. Sweden.

Blomberg, M. 1993. Researcher, Swedish Institute of Agricultural Engineering (SIAE). Personal communication. Uppsala, Sweden.

Bogballe. 1985. Manufacturers brochure.

Dalemo, M. 1993. Researcher, SIAE. Personal communication. Uppsala. Sweden

Elinder, M and Falk, C, 1983. labour and machine data in agriculture. Department of Agricultural Engineering. Swedish University of Agricultural Sciences. Uppsala.Sweden.

FAO.1990. Energy consumption and input-output relations of field operations. CNRE Study no.3. Rome.

Fluck, R.C. 1992. Editor. Energy for farm production Vol. 6 of Energy for world Agriculture. Elsevier. Amsterdam.

Gisebo. 1990. Manufacturers brochure.

Hadders, G. 1989. Harvest, storing and handling of grasses for fuels. Report 426. SIAE. Uppsala. Sweden.

Hadders, G. 1993. Researcher, SIAE. Personal communication. Uppsala.Sweden.

JF. 1985. Manufacturers brochure.

National Machine Testing Institute (NMTI).1985-1992. Reports number 2987, 3091, 3217, 3230, 3254, 3307, 3311. Uppsala. Sweden.

Pimentel, D. 1980. Handbook of energy utilisation in agriculture. CRC press. Florida. U.S.A.

Sonesson, U. 1993. Energy analysis of biofuels from winter wheat, rape seed and salix. Department of Agricultural Engineering. Swedish University of Agricultural Sciences. Uppsala. Sweden.

Stout, B. 1990. Handbook of energy for world agriculture. Elsevier. Amsterdam.

Sundquist, G. 1993. Personal communication. Lmb. Malmö. Sweden.

Swedish National Board for Industrial and Technical Development (NUTEK). 1992. Energy in Sweden, Facts and Figures. Stockholm.

Swedish University of Agricultural Sciences (SLU). 1989. Data book for management planning. Uppsala. Sweden.

Thyselius, l. 1993. Researcher. SIAE. Personal communication. Uppsala. Sweden.

Väderstad. 1985. Manufacturers brochure.

Överum. 1985. Manufacturers brochure.

TABLES

Table 1.Energy equivalents of inputs and outputs.

Inputs	MJ/Unit	Reference
Diesel (l)	47.8	Fluck, 1992
Machinery (kg)	109.0	Fluck, 1992
Barley (kg)	14.9	Fluck, 1992
Fertiliser N (kg)	43.2	Bertilsson, 1992
Fertiliser P (kg)	15.0	Fluck, 1992
Fertiliser K(kg)	9.0	Fluck, 1992
Grass seed (kg)	14.9	Fluck, 1992
Straw (kg of DM)	14.5	Fluck, 1992
Canary grass (kg of DM)	14.5	Fluck, 1992
Biogas (m^3)(1 bar, 20°C)	22.0	Stout, 1990
Plastic (kg)	100.0	Fluck, 1992

Table 2. Energy utilisation in reed canary grass production

Inputs	Units per hectare and year	MJ/ha	% of total
N Fertiliser, kg	100	4 320	48.9
Diesel fuel, l	64.8	3 097	35.1
Machinery, kg[1]	10.1	1 101	12.5
K Fertiliser, kg	20	180	2.0
P Fertiliser, kg	8	120	1.3
Seed , kg[2]	1	15	0.2
Total input, MJ		8 833	100
Yield, MJ		65 250	
Net Energy Gain		56 417	
Output/Input ratio		7.4	

[1] This considers the weight of the machines (kg), its useful life (h), and its effective field capacity (h/ha), see page 4, Identification and quantification of inputs and outputs.

[2]Ten kg is used in year 1 of the ten year cycle.

Table 3. Distribution of machinery and fuel energy in the different operations to produce canary grass. MJ/ha and year.

Operation	Machinery	Fuel	Total	% of total
Ploughing[1]	162.5	33.6	196.1	4.7
Harrowing[1]	98.0	29.5	127.5	3.0
Fertiliser transport	49.0	5.2	54.2	1.3
Fertiliser spreading	183.1	30.1	213.2	5.1
Seeding[1]	41.3	12.2	53.5	1.3
Rolling[1]	21.5	13.2	53.5	1.3
Cutting	528.2	141.6	669.8	16.0
Baling	922.0	496.2	1418.2	33.8
Bales, handling and transport	1092.2	339.0	1431.2	34.0

[1] Carried out only in year 1, therefore the total was divided by 10.

Table 4. Energy utilisation in biogas production from ley silage.

Inputs	Units per hectare and year[2]	MJ/ha	% of total
Diesel fuel, l	224	10 720	38.4
Digester warming, MJ	5 925	5 925	21.2
Machinery, kg	42	4 600	16.5
Pumping, MJ	2 963	2 963	10.6
Plastic, kg	25.0	2 500	8.9
Grain seed, kg [1]	45	670	2.4
Grain drying, MJ [1]	360	360	1.3
Fertiliser P, kg [1]	11.5	173	0.6
Ley seed, kg [1]	2.5	37	0.1
Total input		27 948	100
Outputs			
Grain, kg [1]	850	12 665	15.6
Straw, kg [1]	575	8338	10.3
Methane gas, m^3 (1 bar, 20°C)	1560	59 250	73.2
N surplus, kg	15	648	0.8
Total output		80 901	100
Net Energy Gain		52 953	
Output/input ratio		2.89	

[1]This is the total divided by the four years that the system lasts.

Table 5. Distribution of machinery and fuel energy in the different operations to produce ley for the digester. MJ/ha and year.

Operation	Fuel	Machinery	Total	% of total
Silage handling and transport.	2 814	963	3 777	24.7
Chopping/baling	2 016	982	3 598	23.5
Liquid residues, transport and handling	1 269	1 031	2 300	15.0
Tillage and seeding [1]	1 306	328	1 634	10.6
Solid residue spreading	1 049	421	1 470	9.6
Cutting/conditioning	874	234	1 108	7.2
Straw baling and handling	400	215	615	4.0
Grain harvest and handling	392	111	503	3.3
Digester, manufacture		315	315	2.1
Total	10 720	4 600	15 320	100

[1] Carried out only in year one, therefore the total is divided by four.