Project no. **SES6-CT-2004-502824**

Project acronym: **CROPGEN**

Project title: **Renewable energy from crops and agrowastes**

Instrument: Specific Targeted Research Project

Thematic Priority: SUSTDEV: Sustainable Energy Systems

D9: A European Energy Crops database for AD

Final report

Due date of deliverable: Months 36
Actual submission date: Months 36

Start date of project: 01/03/2004 Duration: 39 months

Organisation name of lead contractor for this deliverable

University of Southampton (Soton)

Revision [0]

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Overview

When considering which crops to grow as feedstocks for anaerobic digestion it becomes apparent that there is no single crop which is the best one for all circumstances. As indicated in the report for work package 1 changes in location lead to different climates and soil types which have a considerable effect on crop growth. Species that are ideal in a central European environment may perform differently in a Mediterranean climate.

Data was collected for a range of plant species which could be grown as crops for energy production in Europe. These species included some which are currently identified as weed species but have good yield potential for biomass or methane. For a sustainable cropping regime it is necessary to 'mix' crops in the farming environment mono cropping, the growing of a single crop repeatedly in the same field, requires intensive application of fertilisers and pesticides and can lead to deficits of nutrients within the soil and damage to the soil structure. On this basis species were also included which produced less yield but could be integrated into cropping systems to improve soil conditions and improve diversity.

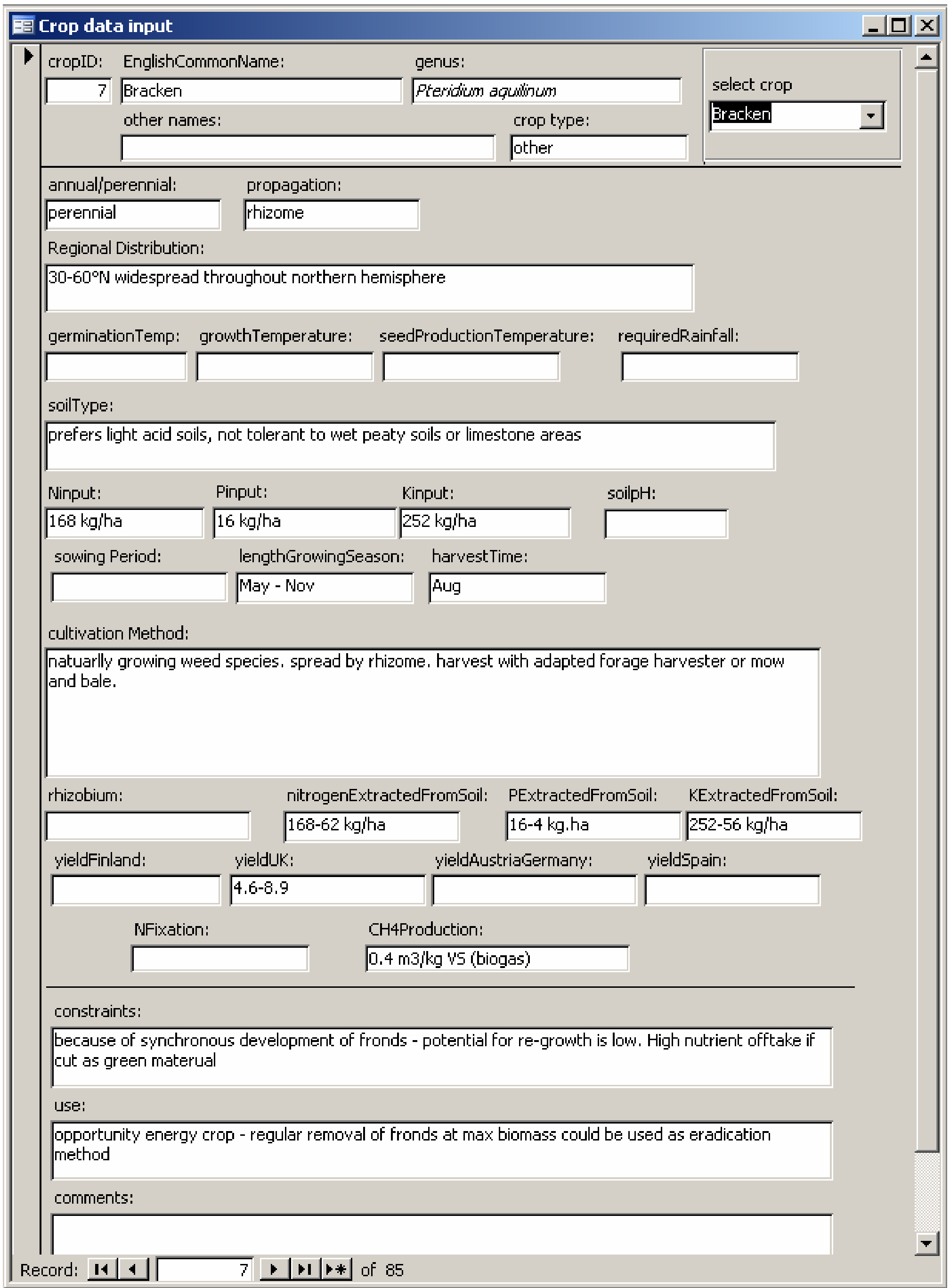
When examining the potential of a renewable energy source it is important that the energy required to produce and process the feedstock is less than that contained in the fuel and by-products produced. various studies have been made of the energy requirements for different field operations used in the production of a crop (for example sowing, fertilising and harvesting). Using knowledge of the operations required it is possible to determine how much energy will be consumed in terms of fuel used and in construction and maintenance of the equipment. Although it is not possible to produce a model which caters for every field according to slope, soil type etc, it is possible to derive a representative energy requirement which can then be used for comparisons between fuel types or alternative crops grown in the same locations. Recommended fertiliser requirements are given for each crop and from these energy requirements for the production of the fertiliser can be determined.

Once the harvested biomass is known and the various characteristics of the feedstock derived from data contained in the database, the energy required for digestion and amount of biogas produced can be calculated. The energy required for production of the feedstock can be added to the requirement for fuel processing/production and an energy balance determined. Biogas has multiple potential uses including electricity and heat production through use in a combined heat and power (CHP) unit or as vehicle fuel once the impurities and excess CO_2 have been removed. This figure is represented in terms of km of travel avail per ha of crop grown.

Potential plant species for use in anaerobic digestion

Information for 85 plant species and sub-species was collected from a range of sources including (El Bassam, 1998, Williams, 1995, Gunaseelan, 2004, Lehtomäki *et al.*, 2003, NIAB, 2004, Purdue University, 2004, Duke, 1983, IENICA, 2004, NNFCC, 2004, FAO, 2004, Milne *et al.*, 2002, Heiermann *et al.*, 2002, Nix *et al.*, 2004, Pouech *et al.*, 1998, Callaghan *et al.*, 1980). The amount of information varies between species according to previous research and the species current use as an agricultural crop. The information for a single species may have been collated from a number of sources. Where a species forms a major part of the food requirement (such as wheat or rice) more research ahs been done than on those with less value such as agrostis grassland (*Agrostis spp.*) or bilberry (*Vaccinium myrtillus*). The information available can be viewed as either an Access database form or printed out as a report. An example of the data input form is shown in

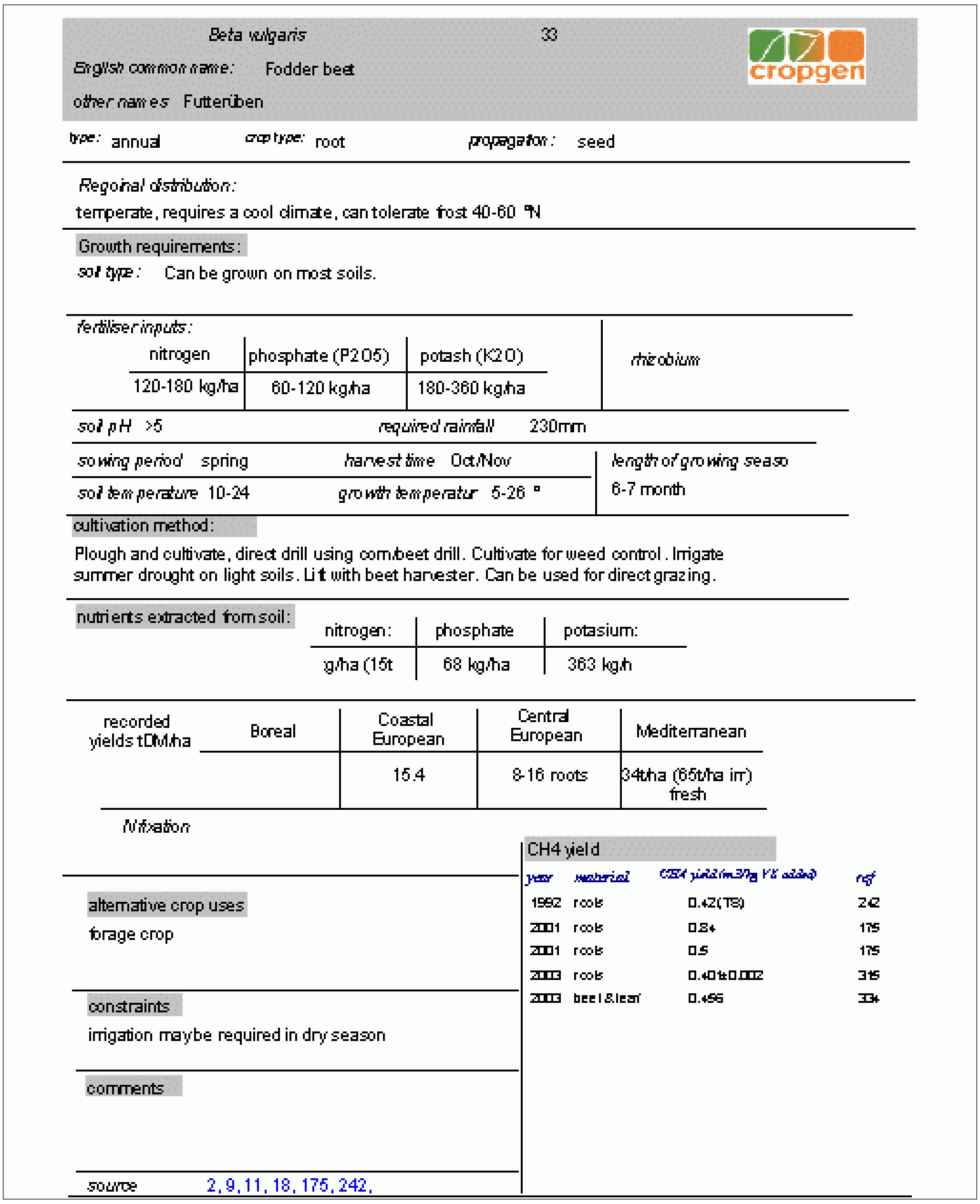
Error! Reference source not found. Figure 1 and an example of the output report is shown in Figure 2.


Crop data input

cropID: 7
EnglishCommonName: Bracken
genus: *Pteridium aquilinum*
select crop: Bracken
other names:
crop type: other
annual/perennial: perennial
propagation: rhizome
Regional Distribution: 30-60°N widespread throughout northern hemisphere
germinationTemp:
growthTemperature:
seedProductionTemperature:
requiredRainfall:
soilType: prefers light acid soils, not tolerant to wet peaty soils or limestone areas
Ninput: 168 kg/ha
Pinput: 16 kg/ha
Kinput: 252 kg/ha
soilpH:
sowing Period:
lengthGrowingSeason: May - Nov
harvestTime: Aug
cultivation Method: natuarlly growing weed species. spread by rhizome. harvest with adapted forage harvester or mow and bale.
rhizobium:
nitrogenExtractedFromSoil: 168-62 kg/ha
PExtractedFromSoil: 16-4 kg.ha
KExtractedFromSoil: 252-56 kg/ha
yieldFinland:
yieldUK: 4.6-8.9
yieldAustriaGermany:
yieldSpain:
NFixation:
CH4Production: 0.4 m3/kg VS (biogas)
constraints: because of synchronous development of fronds - potential for re-growth is low. High nutrient offtake if cut as green materual
use: opportunity energy crop - regular removal of fronds at max biomass could be used as eradication method
comments:
Record: 7 of 85

Figure 1: Form for entering species data

Where information has been obtained for the methane potential of a species that is also shown on the printable report. There maybe a number of different values for a single species depending on experimental procedure used and the growth stage at which the material is harvested. Further details of some of the species shown here can be found in deliverable **D4** which is a database of biochemical methane potentials derived as part of work package 2 of the project.



Beta vulgaris 33

English common name: Fodder beet

other names Futterüben

type: annual crop type: root propagation: seed

Regional distribution:
temperate, requires a cool climate, can tolerate frost 40-60 °N

Growth requirements:
soil type: Can be grown on most soils.

fertiliser inputs:

nitrogen	phosphate (P2O5)	potash (K2O)	rhizobium
120-180 kg/ha	60-120 kg/ha	180-360 kg/ha	

soil pH >5 required rainfall 230mm

sowing period spring harvest time Oct/Nov length of growing season 6-7 month

soil temperature 10-24 growth temperature 5-26 °

cultivation method:
Plough and cultivate, direct drill using corn/beet drill. Cultivate for weed control. Irrigate summer drought on light soils. Lift with beet harvester. Can be used for direct grazing.

nutrients extracted from soil:

nitrogen:	phosphate	potasium:
g/ha (15t	68 kg/ha	363 kg/h

recorded yields tDM/ha	Boreal	Coastal European	Central European	Mediterranean
		15.4	8-16 roots	34t/ha (65t/ha irr) fresh

N fixation

CH4 yield

year	material	CH4 yield (m3/kg VS added)	ref
1992	roots	0.42(TS)	242
2001	roots	0.34	175
2001	roots	0.5	175
2003	roots	0.401±0.002	315
2003	beet &leaf	0.456	334

alternative crop uses
forage crop

constraints
irrigation maybe required in dry season

comments

source 2, 9, 11, 18, 175, 242,

Figure 2:Crop data in printable report view

Information is also included on cultivation methods, sowing and harvest periods and recommended fertiliser inputs. The fertiliser inputs will vary according to soil type and previous cropping so provide only an indication of required amounts, individual farmers will have better appreciation of what is required in their conditions. Similarly yields stated are only indicative of potential and will vary according to circumstance.

Comparison can be made between crops as shown in Figure 3 and Figure 4. This option allows the user to compare the requirements for different species in order to determine which may be more suitable for their conditions.

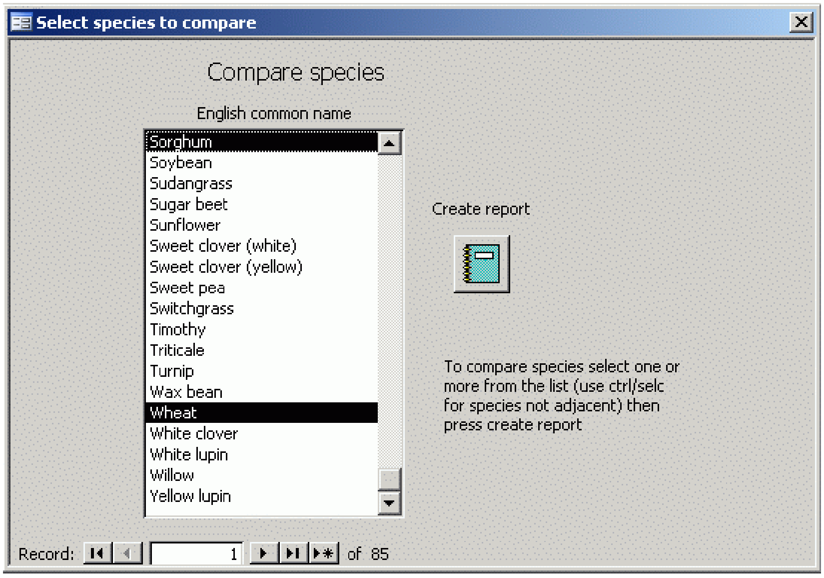
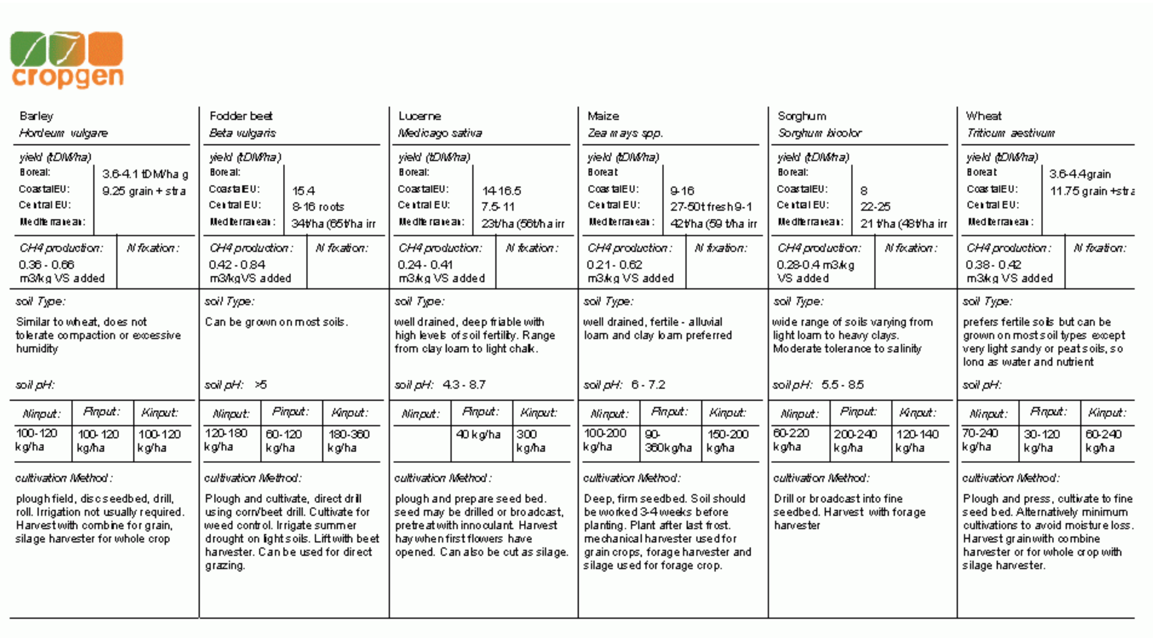


Figure 3: Selecting species for comparison



	Barley *Hordeum vulgare*	Fodder beet *Beta vulgaris*	Lucerne *Medicago sativa*	Maize *Zea mays spp.*	Sorghum *Sorghum bicolor*	Wheat *Triticum aestivum*
yield (tDM/ha) Boreal:	3.6-4.1 tDM/ha g					3.6-4.4grain
yield (tDM/ha) CoastalEU:	9.25 grain + stra	15.4	14-16.5	9-16	8	11.75 grain +stra
yield (tDM/ha) Central EU:		8-16 roots	7.5-11	27-50t fresh 9-1	22-25	
yield (tDM/ha) Mediterranean:		34t/ha (65t/ha irr	23t/ha (56t/ha irr	42t/ha (59 t/ha irr	21 t/ha (48t/ha irr	
CH4 production:	0.36 - 0.66 m3/kg VS added	0.42 - 0.84 m3/kgVS added	0.24 - 0.41 m3/kg VS added	0.21 - 0.62 m3/kg VS added	0.28-0.4 m3/kg VS added	0.38 - 0.42 m3/kg VS added
N fixation:						
soil Type:	Similar to wheat, does not tolerate compaction or excessive humidity	Can be grown on most soils.	well drained, deep friable with high levels of soil fertility. Range from clay loam to light chalk.	well drained, fertile - alluvial loam and clay loam preferred	wide range of soils varying from light loam to heavy clays. Moderate tolerance to salinity	prefers fertile soils but can be grown on most soil types except very light sandy or peat soils, so long as water and nutrient
soil pH:		>5	4.3 - 8.7	6 - 7.2	5.5 - 8.5	
N input:	100-120 kg/ha	120-180 kg/ha		100-200 kg/ha	60-220 kg/ha	70-240 kg/ha
P input:	100-120 kg/ha	60-120 kg/ha	40 kg/ha	90-360kg/ha	200-240 kg/ha	30-120 kg/ha
K input:	100-120 kg/ha	180-360 kg/ha	300 kg/ha	150-200 kg/ha	120-140 kg/ha	60-240 kg/ha
cultivation Method:	plough field, disc seedbed, drill, roll. Irrigation not usually required. Harvest with combine for grain, silage harvester for whole crop	Plough and cultivate, direct drill using corn/beet drill. Cultivate for weed control. Irrigate summer drought on light soils. Lift with beet harvester. Can be used for direct grazing.	plough and prepare seed bed. seed may be drilled or broadcast, pretreat with innoculant. Harvest hay when first flowers have opened. Can also be cut as silage.	Deep, firm seedbed. Soil should be worked 3-4 weeks before planting. Plant after last frost. mechanical harvester used for grain crops, forage harvester and silage used for forage crop.	Drill or broadcast into fine seedbed. Harvest with forage harvester	Plough and press, cultivate to fine seed bed. Alternatively minimum cultivations to avoid moisture loss. Harvest grain with combine harvester or for whole crop with silage harvester.

Figure 4: An example output of data for a comparison of selected crop species

Determination of energy balance.

The second part of the database allows determination of the energy requirements for crop production. The database allows the user to select one species for calculation of energy values and then requires the input of various information relating to part of crop harvested, soil types and fertiliser requirements based on the index level of the soil (how much nutrient already exists in the soil from the previous harvest). By selecting one of four regions (coastal, central, southern or northern) an indicative yield will shown, if available, otherwise the user can input their own yield figure. Selection of harvested part (whole crop, grain etc) results in different field operations being made available from which the user can select those required. Some operations such as ploughing will require different energy inputs according to soil type. An example of the selection and input screen is shown in Figure 5.

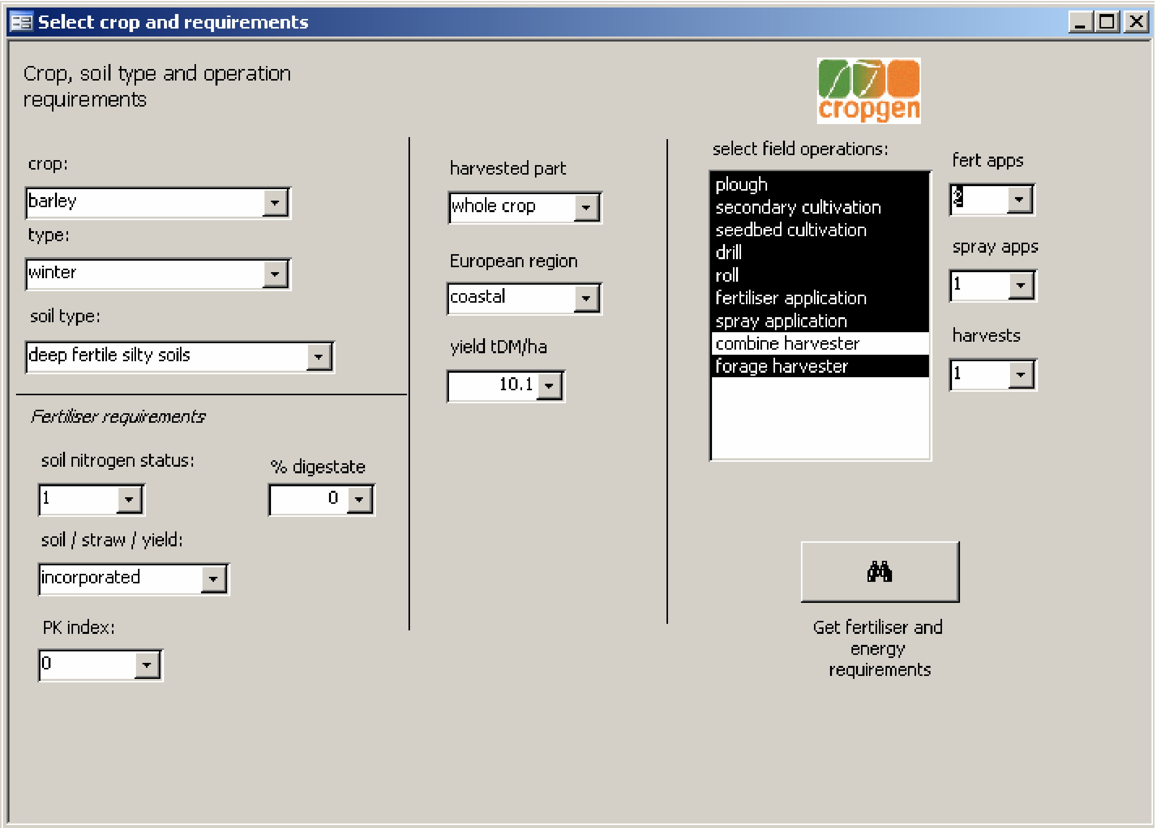


Figure 5: crop selection and input form

Having selected the relevant crop, growth conditions, harvested part, yield, field operations an energy balance is calculated and is presented on the form as shown in Figure 6.

The recommended amount of mineral fertiliser (derived from fossil fuels) required are shown in the Fertiliser sub-form, the energy for fertiliser requirement is based on values from Kongshaug (1998) including 40.3 MJ/kg for nitrogen. The energy required for cultivation depends on the field operations selected and is shown in detail in the Cultivation sub-form. The energy produced is calculated according to the methane yield per tonne of material and the yield per hectare.

Production energy varies according to the design of the digester used, its size, local climate conditions and method of operation. The most common form of digester currently used for farm based production of energy are of the continuously stirred tank reactor (CSTR) design which have been reported in work packages WP4, WP8 and WP9. These digester systems require heat and electricity to run (parasitic energy) and for these calculations the value of this parasitic energy is taken as being 14.4% of the energy of the methane produced.

Having derived the crop production and fuel production energies, a net energy yield is calculated for each ha of feedstock added to the digester. This energy value is shown as potential output if the biogas is converted in a CHP unit to produce heat and electricity or converted into vehicle fuel. These values are shown on the Energy Use sub-form shown in Figure 6.

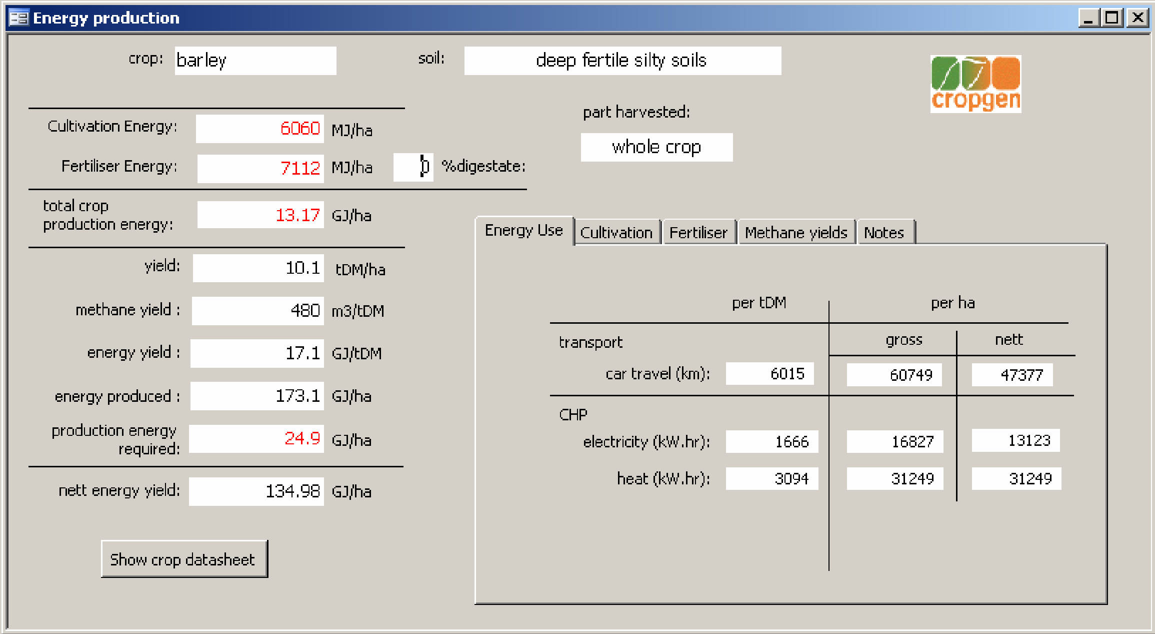


Figure 6: Energy balance form

The use of mineral fertiliser can have a large effect on the energy balance, this can be reduced through the use of digestate which acts as a bio-fertiliser. It is possible to select the proportion of fertiliser that will be applied in the form of digestate on the crop selection form and this is reflected in the energy balance. Figure 7 shows the same inputs as Figure 6 but with 50% of the fertiliser being in the form of digestate.

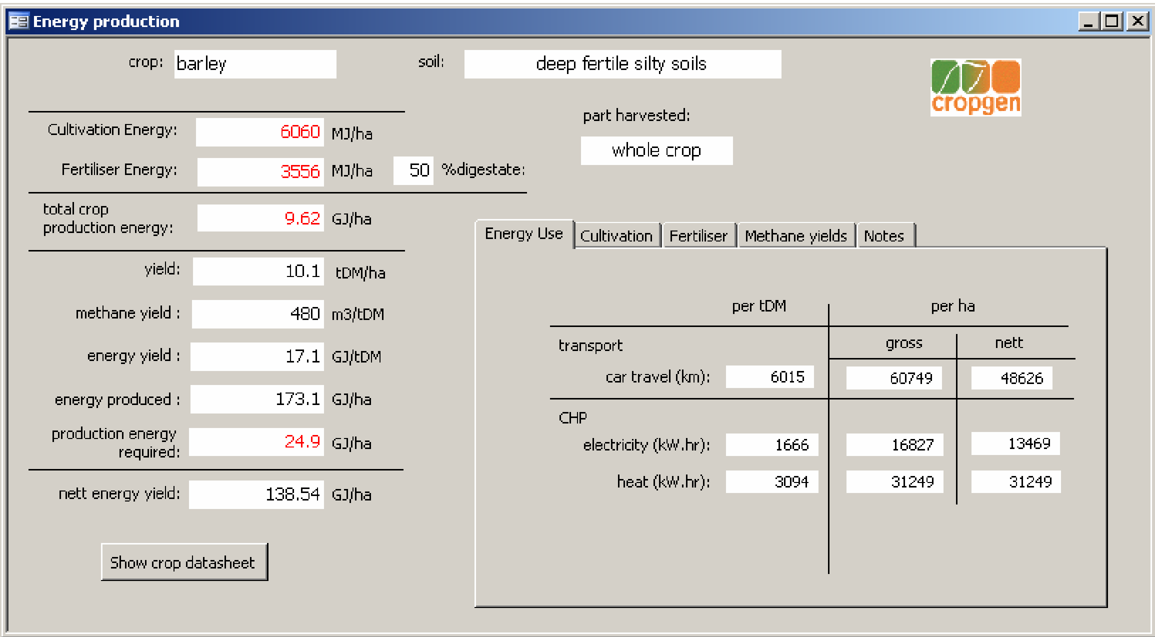


Figure 7: Energy balance using 50% digestate

Conclusion

The energy crops database can be used to provide information regarding growing conditions and potential yields. It also provides a method to compare differences between plant species in terms of required growing conditions and potential energy balances when used as feedstocks for anaerobic digestion. The information provided can only be considered as an indication of potential yields, the actual biomass and biogas yields will be dependent on growing conditions, times of harvest and the configuration of the digester and post processing systems used.

References

Callaghan, T. V., Lawson, G. J., Scott, R. & Whittaker, H. A. (1980) Fuels from Non-woody Plants. IN Twidell, J. (Ed.) *Energy for Rural and Island Communities.* Oxford, Pergamon Press.

Duke, J. A. (1983) *Handbook of Energy Crops*, unpublished.

El Bassam, N. (1998) *Energy Plant Species: Their Use and Impact on Environment and Development*, London, James & James.

Fao (2004) *Grassland Index* [online] Available from: http://www.fao.org/ag/AGP/AGPC/doc/Gbase/mainmenu.htm [Accessed 16/11/2004].

Gunaseelan, V. N. (2004) Biochemical Methane Potential of Fruits and Vegetable Soild Waste Feedstocks. *Biomass and Bioenergy,* 26**,** 389-399.

Heiermann, M., Plöchl, M., Linke, B. & Schelle, H. (2002) Preliminary Evaluation of Some Cereals as Energy Crops for Biogas Production. IN Sayigh, A. A. M. (Ed.) *World Renewable energy Congress VII (WREC 2002).*

Ienica (2004) *Crops database* [online] Available from: http://www.ienica.net/cropsdatabase.htm [Accessed 21/10/2004].

Kongshaug, G. (1998) Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production. *IFA Technical Conference.* Marrakesh, Morocco, International Fertilizer Industry Association.

Lehtomäki, A., Viinikainen, T., Alen, R. & Rintala, J. (2003) Methane Production From Energy Crops And Crop Residues: Effect Of Harvest Time And Chemical Composition. *International Nordic Bioenergy 2003.*

Milne, J. A., Pakeman, R. J., Kirkham, F. W., Jones, I. P. & Hossell, J. E. (2002) Biomass production of upland vegetation types in England and Wales. *Grass and Forage Sci,* 57**,** 373-388.

Niab (2004) *Varieties of Grasses & Herbage Legumes: Participants Handbook,* Cambridge, NIAB.

Nix, J., Hill, P. & Edwards, A. (2004) *Farm Management Pocketbook*, London, The Andersons Centre.

Nnfcc (2004) *Crops* [online] Available from: http://www.nnfcc.co.uk/crops/info/englishnames.htm [Accessed 21/10/2004].

Pouech, P., Fruteau, H. & Bewa, H. (1998) Agricultural Crops for Biogas Production on Anaerobic Digestion Plants. *Biomass for Energy and Industry, C.A.R.M.E.N., Proceeding of the International Conference.* Würzburg, Germany.

Purdue University (2004) *NewCROP* [online] Available from: http://www.hort.purdue.edu/newcrop/default.html [Accessed 20/10/2004].

Williams, J. T. (Ed.) (1995) *Cereals and Pseudocereals,* London, Chapman & Hall.

Dissemination

The initial intention of this deliverable was to provide inputs about crops selected for use as feedstock for anaerobic digestion to the European Energy crops InterNetwork. Unfortunately, the European Energy crops InterNetwork is no longer accepting inputs, as shown in the email communications below. The database will therefore be made available to members of the project and disseminated through downloads via the cropgen website.

> Dear Dr. Salter,
>
> The website is still accesible, however, it is not possible to add any new articles or make changes anymore.
>
> Best regards,
> Douwe van den Berg
>
> At 12:39 21-2-2006, you wrote:
>
> > Dear Sirs.
> >
> > Could you please tell me if the European Energy Crops Internetwork is still active?
> >
> > If so, is it possible to add to the BioBase and how?
> >
> > With best regards.
> >
> > Dr Andrew Salter
> >
> > ==
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