

Greenhouse gas emission from agriculture and the possible mitigation by production of energy crops

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Abstract

The current Danish energy plan stipulates a production of 5 PJ from energy crops in 2010. This may be obtained through growing either annual energy crops (e.g. cereals) or perennial energy crops (e.g. willow or miscanthus).

Existing Danish data and the IPCC methodology was used to calculate nitrous oxide emission and carbon sequestration in soil from growing an annual energy crop (triticale) and a perennial energy crop (miscanthus). The calculations for miscanthus were performed separately for miscanthus harvested in both November and April, because the harvest time affects both yields and emissions. The estimates for miscanthus were based on a 20-year duration of the cultivation period. The energy use for growing the crops was included, as was the reduction in CO₂-emission that will result from substitution of fossil fuel (natural gas). The calculations were performed for both a coarse sandy soil and a loamy sand soil. The results were compared with current (reference) practice for growing cereals. There were only minor differences in production and emission between the two soil types.

The area required to produce 5 PJ was smallest for miscanthus harvested in November (c. 25,000 ha), and about equal for triticale and miscanthus harvested in April (c. 32,000 ha). The reduction in nitrous oxide emission compared with cereal production was smallest for triticale (20 kt CO₂-equivalents yr⁻¹) and about equal for miscanthus at the two harvest times (30-36 kt CO₂-equivalents yr⁻¹). Growing miscanthus resulted in a carbon sequestration with the highest rates for miscanthus harvested in April of 100 kt CO₂ yr⁻¹. The energy use for production of triticale was slightly lower than for normal cereal growing, whereas growing miscanthus for harvest in April results in a smaller energy use corresponding to an emission reduction of 20 kt CO₂ yr⁻¹. The substitution of fossil fuel corresponds to 285 kt CO₂ yr⁻¹. Summing all items, growing 5 PJ worth of miscanthus harvested in April results in an emission reduction of 447 kt CO₂ yr⁻¹, growing miscanthus harvested in November gives a reduction of 355 kt CO₂ yr⁻¹, and growing triticale gives a reduction of 265 kt CO₂ yr⁻¹.

Introduction

The emission of greenhouse gases from agriculture constitutes about 22% of the total emissions in Denmark (Olesen et al., 2001b). The efforts in Denmark to reduce nitrogen losses from agriculture to the environment have and will also contribute to reducing emission of nitrous oxide in particular by reducing the amount of nitrogen that is cycled in the system. Agriculture has in a number of areas possibilities for further reducing the total Danish emissions of greenhouse gases. This may work by directly reducing the emission of the gases, including reduction of energy use, and by reducing emissions of methane and nitrous oxide (Smith et al., 2000). It may also work through the adoption of other farming systems that offer possibilities of substituting fossil fuel use and of carbon sequestration in the soil (Olesen et al., 2001a).

Production of biomass for energy in agriculture will result in substitution of fossil fuels in addition to the substitution that occurs from combustion of the existing surplus of straw. In the Danish energy plan, Energy 21, energy crops are assumed to contribute to energy supply from year 2005 increasing to 45 PJ yr⁻¹ in year 2030. The existing estimates do not account for the effect of growing

energy crops on nitrous oxide emissions or on carbon sequestration in soil. Also growing different energy crops will imply different energy use in the production.

This study attempts to quantify the effect of energy crop type and management on total greenhouse gas emissions from energy crop production.

Methods

A comparison has been made on two soil types of growing annual or perennial energy crops with ordinary cereal cropping. The soils were a coarse sandy soil and a loamy sand soil. The ordinary cereal cropping was assumed to be spring barley on the sandy soil and winter wheat on the loamy sand soil. Triticale was selected as the annual energy crop, and miscanthus as the perennial energy crop. For miscanthus two different harvest times were included in the analyses (November and April). With reference to the energy plan, Energy 21, it is assumed that energy crops should contribute 5 PJ by year 2010.

Crop production data

It was assumed for the ordinary cereal production systems that half of the straw was being removed. Spring barley was grown with a catch crop of ryegrass every year. Nitrogen fertilisation was based on mineral fertilisers. On the coarse sandy soil irrigation was applied to both the spring barley and to the annual energy crop, but not to the perennial energy crop. The irrigation was set to 75 mm for spring barley and 105 mm for triticale (Landbrugets Rådgivningscenter, 1990). No irrigation was applied on the loamy sand soil.

The basic data of crop production and nitrogen use and losses are shown in Tables 1 and 2. Grain yields and N application for cereals were based on norms for the particular soils (Plantedirektoratet, 2000). However, yields and N application in triticale were reduced by 10% to account for the lower input level in bioenergy production (Nielsen, 1999). The straw yields in barley and wheat were set to 55 and 65% of the grain yields, respectively (Landbrugets Rådgivningscenter, 1999). The grain yield was set to 45% of total above-ground biomass (Olesen et al., 2000). The biomass in roots was set at 27% of above-ground biomass. The ryegrass catch crop grown with the spring barley was assumed to have contributed an additional 1 t DM ha⁻¹. Data on N contents in grain as straw were taken from Møller et al. (2000).

Miscanthus is a perennial crop with a slow growth during the establishment phase (1-3 years). Different values of crop production and of inputs were therefore used for each of the first three years and then a common value for the following years. A total production period of 20 years was used, and Tables 1 and 2 show the production and nitrogen data weighted for this 20-year production period. The data were based on experiments at two sites in Denmark, Jyndevad (coarse sand) and Foulum (sandy loam) (Jørgensen, 1997; Kristensen, 1998; Jørgensen and Kjeldsen, 2000; Jørgensen and Mortensen, 2000). There was a higher production on the coarse sandy soil, primarily caused by warmer conditions at this site.

Nitrate leaching from the cereal crops was estimated using an empirical model (Simmelsgaard, 1998). Ammonia volatilisation was estimated as 2% of the nitrogen in fertiliser plus and additional volatilisation from the crops (Andersen et al., 1999).

Table 1. Annual biomass production (t DM ha⁻¹). The total biomass includes both above- and below-ground biomass. The miscanthus data are average of a 20 year production period.

Soil	Crop	Total	Harvested	Returned
Coarse sand	Spring barley	12.7	5.8	8.0

	Triticale (biomass)	13.8	9.3	4.6
	Miscanthus (November)	20.9	15.3	5.6
	Miscanthus (April)	20.9	10.8	10.1
Loamy sand	Winter wheat	16.8	7.9	8.9
	Triticale (biomass)	13.8	9.3	4.6
	Miscanthus (November)	16.8	12.2	4.6
	Miscanthus (April)	16.8	7.3	9.5

Table 2. Data on annual nitrogen inputs and losses (kg N ha^{-1}). The miscanthus data are average of a 20 year production period.

Soil	Crop	Fertiliser	Returned in crop residues	Ammonia volatilisation	Nitrate leaching
Coarse sand	Spring barley	136	79	8	69
	Triticale (biomass)	118	24	6	63
	Miscanthus (November)	81	38	5	18
	Miscanthus (April)	56	74	4	18
Loamy sand	Winter wheat	166	48	8	62
	Triticale (biomass)	106	24	6	44
	Miscanthus (November)	81	39	5	14
	Miscanthus (April)	56	86	4	14

Energy consumption in the production

The energy consumption for the cereal crops was calculated separately for each soil type using the ØKOBÆR model (Dalgaard et al., 2001). This model was also used for miscanthus, but the management was set to vary over the 20 year growing period, and no separation was made between the two soil types. The energy used for transporting the biomass to the power plant was estimated using a transport distance of 50 km (Nielsen and Mortensen, 2000). The energy use was converted to CO_2 emission using the following emission factors (Dalgaard et al., 2000): diesel $74.0 \text{ kg CO}_2 \text{ GJ}^{-1}$, electricity and machinery $95.0 \text{ kg CO}_2 \text{ GJ}^{-1}$ and fertiliser $56.9 \text{ kg CO}_2 \text{ GJ}^{-1}$.

Fossil fuel substitution

The estimates of the energy content in the biomass were based on the combustion value of the biomass. This value accounts for contents of ashes and water in the biomass (Videncenter for Halm- og Flisfyring, 1993, 2000). The energy content in triticale with 15% water is $16.8 \text{ MJ kg}^{-1} \text{ DM}$. The energy content in miscanthus harvested in November with 55% water is $14.9 \text{ MJ kg}^{-1} \text{ DM}$, and the energy content in miscanthus harvested in April with 15% water is $17.5 \text{ MJ kg}^{-1} \text{ DM}$.

It is assumed that energy crops will substitute natural gas in the energy supply (Audsley, 1997). An emission factor of $56.9 \text{ kg CO}_2 \text{ GJ}^{-1}$ was used for natural gas. It was assumed that the conversion efficiency of energy in biomass is the same as for natural gas. In reality, the efficiency will often be lower for biomass.

Carbon sequestration in soils

The carbon turnover model described below was used to estimate changes in soil carbon storage for a soil with an initial content of 70 t C ha^{-1} in the top 30 cm of the soil. This corresponds to the average measured soil carbon content on Danish arable farms (Heidmann et al., 2000). The relative

differences in change in carbon storage between different crop types are independent of initial C content in the soil. The development in soil carbon content (incl. roots and rhizomes) was calculated over a 20-year period by numerical integration of eqns (4) and (5). The carbon sequestration was then estimated as the average annual increase over the 20 years.

The carbon turn-over in soils was described by a first-order differential equation:

$$\frac{dC}{dt} = hA - kC \quad (1)$$

where C is the soil content of organic carbon (t C ha^{-1}), t is time (years), k is the turnover rate (year^{-1}), h is the humification coefficient, and A is the added organic carbon ($\text{t C ha}^{-1} \text{ yr}^{-1}$).

The development of soil carbon content without addition of organic matter was described by

$$C_t = C_0 \exp(-kt) \quad (2)$$

where C_t is the carbon content at time t , and C_0 is soil carbon content at time 0.

The turnover rate k was estimated at 0.0136 using data for development in carbon content in the bare soil plots of the Askov long-term experiments (Christensen, 1990). The estimation was performed using eqn (2) and the procedure NLIN of SAS (SAS Institute, 1988).

This estimate of turnover rate was for a system with annual soil cultivation. Balesdent et al. (1990) found that the mineralisation in undisturbed soil was only 47% of the mineralisation in normally tilled soils. Smith et al. (1998) found for a range of North European experiments with minimum tillage that avoiding soil tillage caused an annual increase in soil C content of 0.73% of the total carbon content. The results implies that growing perennial energy crops without annual soil tillage will reduce the turn-over rate by 50% to $k = 0.0068$.

The humification coefficient was calculated for experiments with different rates of application of straw. This included three experiments in Denmark carried out over 9 to 23 years (Thomsen, 1995; Christensen and Olesen, 1998) and one experiment in Sweden carried out over 35 years (Kirchmann et al., 1994). The difference in soil carbon content in 0-25 cm depth between plots with and without straw application (ΔC_t) at time t was modelled as

$$\Delta C_t = \sum_{i=1}^t (hA + \Delta C_{i-1}) \exp(-k) \quad (3)$$

The application of carbon in straw was estimated assuming a dry matter content in straw of 85% and a carbon content in dry matter of 45%. The humification coefficient was for the Danish experiments estimated as 0.27 and for the Swedish experiment as 0.23 using eqn (3) and the procedure NLIN in SAS. An average humification coefficient of $h = 0.25$ was used in the model estimations.

Crop production will not only lead to addition of carbon from straw and other above-ground crop residues, but also from below-ground residues. The amount of below-ground crop residues was estimated using data for the difference in carbon content in experimental treatments with removal of all above-ground crop residues and an experimental treatment with bare soil in a Swedish experiment over 35 years (Kirchmann et al., 1994). The experimental treatment with removal of crop residues was part of a cereal-based crop rotation with fertilisation with calcium nitrate. The carbon input was estimated at $1.2 \text{ t C ha}^{-1} \text{ yr}^{-1}$ using eqn (3). The average annual above-ground dry matter yield in cereals in the experiment was 7.0 t ha^{-1} or 3.2 t C ha^{-1} . The carbon input from below-ground residues thus constitute ca. 27% of the total carbon uptake by the crop.

Measurements of ^{13}C -content in soil for an experiment with miscanthus at Hornum in Denmark have shown that the miscanthus derived C-content in 0-30 cm soil depth constitutes 4.6 t C ha^{-1} after 9 years and 14.1 t C ha^{-1} after 16 years of continuous miscanthus cropping (Hansen and Christensen, 2001). There were also considerable amounts of roots and rhizomes in the soil, and these constituted 6.7 t C ha^{-1} and 7.3 t C ha^{-1} after 9 and 16 years of miscanthus, respectively.

To model soil organic matter in miscanthus, a carbon pool of active roots and rhizomes (C_a) are introduced. This pool has a constant turnover rate (m):

$$\frac{dC}{dt} = h(mC_a + hA_o) - kC \quad (4)$$

$$\frac{dC_a}{dt} = A_u - mC_a \quad (5)$$

where C is the soil carbon content (without active roots and rhizomes). A_o is the input of carbon from above-ground plant residues ($\text{t ha}^{-1} \text{ yr}^{-1}$), and A_u is the annual input of carbon to active roots and rhizomes ($\text{t ha}^{-1} \text{ yr}^{-1}$).

The miscanthus crop in the experiment at Hornum was harvested in spring, and it is assumed that the carbon inputs (A_o and A_u) were constant from year four after crop establishment. The inputs were assumed to constitute 1/6, 1/3 and 1/2 of the final input level in years 1, 2 and 3, respectively. The final input level of above-ground plant residues was assumed to be $3.6 \text{ t C ha}^{-1} \text{ yr}^{-1}$. It was also assumed that the turnover rate of soil carbon was only half of the standard value of 0.0136, because no soil tillage was performed. The annual inputs to roots and rhizomes were assumed to be a fixed percentage of the above-ground dry matter production, which based on data from experiments at Foulum was set to $7.2 \text{ t C ha}^{-1} \text{ yr}^{-1}$ after four years of cropping. Using these assumptions and the NLIN procedure of SAS, m in eqns (5) and (6) was estimated at 0.12 and A_u was estimated as 16% of the above-ground carbon production.

Nitrous oxide emissions

The emission of nitrous oxide was calculated using the IPCC methodology (IPCC, 1997). The emission factors were $0.0125 \text{ kg N}_2\text{O-N kg}^{-1} \text{ N}$ for N in fertiliser and crop residues. The emission factor was $0.010 \text{ kg N}_2\text{O-N kg}^{-1} \text{ N}$ for ammonia volatilisation and $0.025 \text{ kg N}_2\text{O-N kg}^{-1} \text{ N}$ for nitrate leaching. The emissions vary over time for miscanthus, and the estimates were therefore calculated as the average of a 20-year period.

Results and discussion

The calculated annual nitrous oxide emissions and changes in soil carbon storage from growing different crops are shown in Table 3. There were large differences between the different crops, but only small differences between the two soil types. The highest emissions reductions were obtained for the Miscanthus crops for all emissions categories.

Table 3. Annual nitrous oxide emissions, energy use and substitution of fossil energy use by growing various crops.

	Cereal cropping	Triticale biomass	Miscanthus November	Miscanthus April
<i>Coarse sandy soil</i>				
Nitrous oxide emission	2.19	1.66	0.97	1.03
CO ₂ -emission from changed soil C	0.19	1.42	-1.87	-3.59
Energy use in crop production	1.11	1.08	0.97	0.51
Substitution of fossil fuel	0.00	-8.85	-12.93	-10.75
Total emission	3.49	-4.69	-12.86	-12.80
<i>Loamy sand soil</i>				
Nitrous oxide emission	2.10	1.36	0.92	1.05

CO ₂ -emission from changed soil C	-0.14	1.42	-1.21	-3.09
Energy use in crop production	1.04	0.75	0.97	0.51
Substitution of fossil fuel	0.00	-8.85	-10.30	-7.27
Total emission	3.00	-5.32	-9.62	-8.80

Table 4. Land area required on an equal mixture of coarse sand and loamy sand soils for production of 5 PJ worth of biomass for energy production. The emission reduction in comparison with conventional cereal production is calculated for nitrous oxide emission, energy consumption, fossil fuel substitution and carbon sequestration. The emission reduction is shown in kg CO₂-equivalents yr⁻¹.

	Triticale biomass	Miscanthus November	Miscanthus April
Area (ha)	32140	24812	32797
Nitrous oxide emission reduction	20	30	36
Soil carbon sequestration	-45	37	108
Reduced energy use	5	3	18
Substitution of fossil fuel	285	285	285
Total emission reduction	265	355	447

Table 4 shows the land required to grow the different bioenergy crops and the associated reductions in greenhouse gas emissions. The area required to produce 5 PJ was smallest for miscanthus harvested in November, and about equal for triticale and miscanthus harvested in April. The reduction in nitrous oxide emission compared with cereal production was smallest for triticale (20 kt CO₂-equivalents yr⁻¹) and about equal for miscanthus at the two harvest times (30-36 kt CO₂-equivalents yr⁻¹). Growing miscanthus resulted in a carbon sequestration with the highest rates for miscanthus harvested in April of 100 kt CO₂ yr⁻¹. The energy use for production of triticale was slightly lower than for normal cereal growing, whereas growing miscanthus for harvest in April results in a smaller energy use corresponding to an emission reduction of 20 kt CO₂ yr⁻¹. The substitution of fossil fuel corresponds to 285 kt CO₂ yr⁻¹. Summing all items, growing 5 PJ worth of miscanthus harvested in April results in an emission reduction of 447 kt CO₂ yr⁻¹, growing miscanthus harvested in November gives a reduction of 355 kt CO₂ yr⁻¹, and growing triticale gives a reduction of 265 kt CO₂ yr⁻¹.

The uncertainties associated with these estimates are probably mostly associated with the estimation of the root-derived carbon and nitrogen, as these were determined indirectly. Also only carbon in the upper 30 cm of the soil is included in the calculations. There are probably differences in the root depth of the different varieties and thus in the sequestration of carbon below this depth. The effect of tillage on soil carbon turnover between the perennial and annual crops is also of major importance and further studies on this is needed.

The reference crop used in these calculations was a cereal crop. There is currently an option in the EU regulation to grow energy crops as an alternative to set-aside. It is expected that the requirement for set-aside will be removed. Set-aside crops of permanent grass will differ considerably from cereal crops with respect to nitrous oxide emissions and carbon sequestration. Further investigations in the effect of reference crops on the estimations of effects of bioenergy crops on greenhouse gas mitigation are thus needed.

There are thus a number of environmental advantages from growing perennial compared with annual energy crops. However, the promotion of perennial energy crops requires a long-term and coordinated strategy involving both technical and political aspects. The individual farmer needs a

clear political signal that energy crops are given priority also in future changes of the agricultural policy. This is required because perennial energy crops takes up the land for a long period of time.

References

- Andersen, J.M. (1999). *Estimering af emission af metan og lattergas fra landbruget*. Miljø- og Energiministeriet. Danmarks Miljøundersøgelser. Arbejdsrapport fra DMU nr. 116.
- Audsley, E. (Ed.) (1997). *Harmonisation of environmental life cycle assessment for agriculture*. Final Report Concerted Action AIR3-CT94-2028. European Commission DG VI Agriculture, Brussels.
- Balesdent, J., Mariotti, A. & Boisgontier, D. (1990). Effect of tillage on soil organic carbon mineralization estimated from ^{13}C abundance in maize fields. *Journal of Soil Science* **41**, 587-596.
- Christensen, B.T. (1990). Sædskiftets indflydelse på jordens indhold af organisk stof. II. Markforsøg på grov sandblandet lerjord (JB5), 1956-1985. *Tidsskrift for Planteavl* **94**, 161-169.
- Christensen, B.T. & Olesen, J.E. (1998). Nitrogen mineralization potential of organomineral size separates from soils with annual straw incorporation. *European Journal of Soil Science* **49**, 25-36.
- Dalgaard, T., Halberg, N. & Fenger, J. (2000). *Simulering af fossilt energiforbrug og emission af drivhusgasser*. FØJO-rapport nr. 5.
- Dalgaard, T., Halberg, N. & Porter, J.R. (2001). A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture Ecosystems & Environment* **87**, 51-65.
- Hansen, E.M. & Christensen, B.T. (2001). Danmarks JordbrugsForskning. Personlig meddelelse.
- Heidmann, T., Nielsen, J., Olesen, S.E., Christensen, B.T. & Østergaard, H. (2000). *Ændringer i indhold af kulstof og kvælstof i dyrket jord: resultater fra kvadratnettet 1987-1998*. DJF rapport Markbrug no. 54.
- IPCC (1997). *Greenhouse Gas Inventories. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change.
- Jørgensen, U. (1997). Genotypic variation in dry matter accumulation and content of N, K and Cl in *Miscanthus* in Denmark. *Biomass & Bioenergy* **12**, 155-169.
- Jørgensen, U. & Kjeldsen, J.B. (2000). *Dyrkning af elefantgræs*. DJF rapport Markbrug 29, 23-29.
- Jørgensen, U. & Mortensen, J. (2000). Kombination af energiafgrødeproduktion og grundvandsbeskyttelse. DJF rapport Markbrug 29, 97-104.
- Kirchmann, H., Persson, J. & Carlgren, K. (1994). *The Ultuna long-term soil organic matter experiment, 1956-1991*. Swedish University of Agricultural Sciences, Department of Soil Sciences, Reports and Dissertations no. 17.
- Kristensen, E.F. (1998). Høst af elefantgræs, *Miscanthus 'Giganteus'*. Grøn Viden Markbrug, nr. 202.
- Landbrugets Rådgivningscenter (1990). *Landskalkuler for de enkelte produktionsgrene. Kalenderårene 1989 og 1990*. Landbrugets Informationskontor.
- Landbrugets Rådgivningscenter (1999). *Håndbog i plantedyrkning 1999*. Landskontoret for Uddannelse. 200 pp.
- Møller, J., Thøgersen, R., Kjeldsen, A.M., Weisbjerg, M.R., Søgaard, K., Hvelplund, T. & Børsing, C.F. (2000). *Fodermiddeltabel. Sammensætning og foderværdi af fodermidler til kvæg*. Landbrugets Rådgivningscenter. Landskontoret for Kvæg. Rapport nr. 91.
- Nielsen, K.V. (1999). *Demonstrations- og udviklingsprogrammet vedrørende produktion og anvendelse af energiafgrøder. Triticale til energi – midtvejsrapport*. Landbrugets Rådgivningscenter, Landskontoret for Planteavl.

- Nielsen, V. & Mortensen, H.S. (2000). *Håndtering af energifgrøderne triticale og elefantgræs*. DJF rapport Markbrug 44.
- Olesen, J.E., Mortensen, J.V., Jørgensen, L.N. & Andersen, M.N. (2000). Irrigation strategy, nitrogen application and fungicide control in winter wheat on a sandy soil. I. Yield, yield components and nitrogen uptake. *Journal of Agricultural Science, Cambridge* **134**, 1-11.
- Olesen, J.E., Andersen, J.M., Jacobsen, B.H., Hvelplund, T., Jørgensen, U., Schou, J.S., Graversen, J., Dalgaard, T. & Fenhann, J. (2001a). *Kvantificering af tre tiltag til reduktion af landbrugets udledning af drivhusgasser*. DJF-rapport Markbrug 48.
- Olesen, J.E., Andersen, J.M., Jacobsen, B.H., Hvelplund, T., Jørgensen, U., Schou, J.S., Graversen, J., Dalgaard, T. & Fenhann, J. (2001b). *Kvantificering af tre tiltag til reduktion af landbrugets udledning af drivhusgasser*. DJF-rapport Markbrug 48.
- Plantedirektoratet (2000). *Vejledning og skemaer, mark og gødningsplan, gødningsregnskab, plantetække, harmoniregler 2000/01*.
- SAS Institute (1988). *SAS/STAT User's Guide*. Release 6.03 Edition. SAS Institute Inc., Cary, NC, USA.
- Simmelsgaard, S.E. (1998). The effect of crop, N-level, soil type and drainage on nitrate leaching from Danish soil. *Soil Use and Management* **14**, 30-36.
- Smith, P., Powlson, D.S., Glendining, M.J. & Smith, J.U. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. *Global Change Biology* **4**, 679-685.
- Smith, P., Goulding, K.W.T., Smith, K.A., Powlson, D.S., Smith, J.U., Falloon, P. & Coleman, K. (2000). Including trace gas fluxes in estimates of the carbon mitigation potential of UK agricultural land. *Soil Use and Management* **16**, 251-259.
- Thomsen, I.K. (1995). Catch crop and animal slurry in spring barley grown with straw incorporation. *Acta Agriculturae Scandinavica, Section B* **45**, 166-170.
- Videncenter for Halm- og Flisfyring (1993). *Beregning af brændværdi ved forskellige vandindhold*. Videnblad nr. 69.
- Videncenter for Halm- og Flisfyring (2000). *Brændselsdata*. Videnblad nr. 155.