Acta Agronomica Óváriensis Vol. 59. No.2.

Introduction to fossil free grain production

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SUMMARY

Agriculture is a crucially important industry for mankind. This is the industry that has been with us since the dawn of history, producing products that are indispensable to our lives. It is therefore crucial that the system should remain sustainable in its energy use, not only at a given moment in time, but also over the long term.

Within agriculture, the area of grain production has been of primary importance both economically and in terms of territory. In Hungary 56% of arable land in 2017 was used for grain production, of which the vast majority was given over to winter wheat and maize, over a total area of almost 2 million ha. These two grains also carry enormous significance worldwide. Due to their great importance, we examined the energy balance of the production of these two grains.

In contrast to the current open energy system, we examined how the energy balance of the system would develop under a closed system. The closed system relies exclusively on biogas produced from the straw or maize stalks remaining as by-products of farming, as energy inputs. This can be used directly for fertilizer production and as fuel, or indirectly as a fuel used in heat or electricity generation. It can be calculated whether the by-products produced from one hectare of arable land, could be used to entirely cover the energy needs of the production, or in what way the energy balance would change compared with the current one.

In the course of the study, it was found that in the case of maize, the largest energy demand was from nitrogen-based fertilizer (more than a quarter of the total energy demand). In the case of wheat, partly due to the plant's lower nitrogen needs, and partly due to technology, the total amount of energy consumed is less than in the case of maize. However, the amount of biogas that can be obtained from wheat straw is lower than that from maize.

The study assumes that the energy use of by-products will occur only through biogas technology, meaning it could be done in a decentralized manner.

Keywords: energy balance, biogas, biogas-based power generation, maize production, wheat production

INTRODUCTION AND LITERATURE REVIEW

In Hungary, according to the official 2017 data, there were 4,33 million ha of arable land, of which 56% was used to grow grain (*Hungarian Central Statistical Office*, 2017). The two most important grains were maize and wheat. The area of the former was 1.0 million ha, while the latter occupied 908 thousand ha. In the past few years this value has shown a slightly downward trend, but nevertheless these two grains remain the two largest crops, covering a total area of 1,9 million ha, or 20,51% of the total area countrywide (*Hungarian Central Statistical Office*, 2017).

These crops are also of great importance worldwide: according to the FAO data, 229,1 million ha of maize and 221,0 million ha of wheat were produced in the world (the latter does not include only winter wheat, as it does in Hungary) (*FAO*, 2017).

Bearing in mind the continuing growth of the world's population,it is crucial for the production of the above two grains to remain energetically sustainable. The worldwide population's demand for wheat and maize can only be ensured through integrated crop production methods. Without nitrogen-based fertilizers, the food needs of only about half of the world's population could be met. (*C.J. Dawson et al*, 2011). Since population growth is unceasing, nitrogen fertilizers are of paramount importance.In terms of energy, they are a significant factor in production, in the case of maize production the energy demand of N-fertilizers accounts for more than a quarter of the total energy used (*Horvath T. et al*, 2018). For this reason it is worth addressing nitrogen fertilizers separately.

One of the main problems of industrial agricultural production is the huge demand for and dependence on the fossil fuel based N-fertilizer production (*Carl F. Jordan*, 2016).

It is important to know and examine the fact that the natural gas used for fertilizer production suffers shrinkage (leaks) at several points during overland transport. *N. G. Phillips et al* (2013) produced a study of USA losses in gas transportation, and the *International Energy Agency* (2006) produced studies of Russian losses, both of which had values between 3-8%, though both studies also indicated a likely deviation between the data provided by the operators and reality, to the extent that real losses are likely to be higher. For this reason, we elected to use the 8% figure in the studies, though we can suppose that even this loss is less than the real figure.

Beyond this, additional energy needs arise during production from seed sowing through the transportation used in harvesting, which would mainly be in the form of fuel use.

The Slovak *Bartalos* (2016) and *Pimentel* (2009) from the USA produced energy balance studies based on *Neményi* (1983) and *Pimentel* (1980), which can be used as a basis for the comparison of the results of our model, which examines the two most important and widely planted grains in Hungary in a closed, energetically balanced self-sustaining system. Because nitrogen-based fertilizer is an important raw material for integrated agricultural production, the study also sheds light on the amount of greenhouse gas that is released into the air in conjunction with use of the nitrogen-based fertilizer due to the transport losses alone, which could be avoided if a closed system were used.

MATERIALS AND METHODS

In determining energy requirements, we have elected to separately consider the energy requirements of manufacturing nitrogen-based fertilizer and the energy needs of other energy inputs, due to the transportation-related fuel losses incurred in the course of manufacturing. We separately calculated the maize and winter wheat energy balances in the traditional production process, as well as under a supposed closed energy system.

The closed production system assumed in the model is based on the byproduct of the given grain. In the case of maize, this is the stalk and the husk, in the case of winter wheat this is the wheat straw. As regards biogas production, the byproduct was considered as the only input. We bring the fact into relief, that in practice, in the course of biogas production, in order to keep the ratio of C:N at an optimal level, other byproducts are also required (for example food waste, byproducts or blown food from food industry, or manure from farms), however even in its present form the model is a good reflection of the energy potential of the closed system.

In making our model, we have taken into account those sources which provide realistic input and output data derived from scientific and practical experience. An additional assumption of the model is that the energy content of the byproduct, and the energy used for harvesting, transporting, and storing the same, is greater than the input energy.

Following the calculation of the amount of natural gas required for the nitrogen fertilizer production, the carbon dioxide equivalent to the amount of additional greenhouse gas emissions which can be spared through elimination of shipping losses incurred during natural gas transportation alone.

INPUT ENERGY NEEDS

According to the calculations of *Pimentel* (2009), 1 ha of maize has an associated energy input total of $e_{inp} = 34.449\ [MJ/ha]$, while on the basis of the data of *Bartalos* (2016), the average of this value is $e_{inp} = 20.757\ [MJ/ha]$.The input values can vary by approx. +/-15% depending on the soil cultivation method and the amount of manure that is used. We used average values for the calculation.

In the case of wheat, by averaging Pimentel’s data of $e_{inp} = 17.905\ [MJ/ha]$ with Bartalos’s data, the total energy input is calculated at $e_{inp} = 14.095\ [MJ/ha]$.

These values do not take into account the transport-related losses of natural gas associated with the production of nitrogen fertilizer.

The energy required to produce the nitrogen-based fertilizer can be calculated. The methane demand of the Haber-Bosch process which is used in fertilizer production is known, in the technical literature modern fertilizer production of 1 kg of nitrogen requires $e_{N-fert} = 35\ [MJ/kg]$ natural gas, including all requirements associated with every manufacturing process involved, insofar as the fertilizer plant’s energy input is exclusively natural gas (*Alghren et al.*, 2010).

The transportation losses of $r_{loss,gas} = 8\%$ must also be accounted for, on the basis of the following formula:

$$e_{lost,gas} = \left(r_{loss,gas} \times e_{N-fert}\right) - e_{N-fert}$$

In other words, the yielded nitrogen fertilizer for each kg results in 2,8 MJ of natural gas (0,081 m^3) leaking into the atmosphere as shipping losses. If we further add this to the energy requirement, then the full energy input of normal (not closed system) production changes as summarized in *Table 1*.

Table 1: Energy input needs of maize and wheat production

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Total input (E_{inp})	21.124 MJ/ha	34.860 MJ/ha	14.405 MJ/ha	17.701 MJ/ha
- of which energy needs of nitrogen fertilizer	5.670 MJ/ha	5.859 MJ/ha	4.196 MJ/ha	2.586 MJ/ha
Fraction of nitrogen fertilizer out of total energy input	26,8%	16,8%	29,1%	14,6%

The quantity of nitrogen fertilizer yielded during wheat production depends greatly on the previous crop, as well as the method of farming. In European practice, larger yielded quantities are the norm, while in USA lower quantities can be assumed. On the basis of experience in Hungary, between 65 kg/ha and 111 kg/ha of nitrogen fertilizer were used depending on the previous crop, which matches Bartalos's values for Slovakia. In the case of the USA the average is 68,4 kg/ha (*Pimentel*, 2009). In analyzing the Hungarian data, we calculated using the largest values taking into consideration practical experience with the model.

YIELD, QUANTITY OF BYPRODUCT THAT CAN BE USED

Besides input factors, the other important starting point in our model is the amount of byproduct of maize or wheat production. Under the closed production system under consideration within our model, this serves as the exclusive energy source. Current energy production and conversion technologies are already capable of meeting fuel needs from the biogas directly, or using electronic energy developed with biogas.

The yields from grain and its byproducts are shown in *Table 2*.

While for maize production in USA, Pimentel's study shows an average of $Y_{grain} = 9.400[kg/ha]$, in Hungary taking into account the past three years of production, $Y_{grain} = 7.413\ [kg/ha]$ can be used to calculate 15% ($f_{grain} = 0{,}15$) moisture content (*Hungarian Central Statistical Office*, 2017). The situation is the reverse in terms of wheat. While in USA the average production was $Y_{grain} = 2.900\ [kg/ha]$, in Hungary taking into account the average over the past three years, this value was $Y_{grain} = 5.330\ [kg/ha]$ (*Hungarian Central Statistical Office*, 2017). In this case we calculated with a 14% moisture content ($f_{grain} = 0{,}14$).

In the case of maize, a ratio of 1:1 seed / stem ($r_{stalk} = 1{,}0$), while for wheat 0,945:1 seeds/stalkwere assumed ($r_{stalk} = 0{,}945$) as applied to clean, dry product. This can be used to calculate the expected quantity of byproduct as follows:

$$Y_{stalk,dry} = Y_{grain} \times \left(1 - f_{grain}\right) \times r_{stalk} = 6.301\ [kg/ha]$$

Table 2: Biomass yields of maize and wheat production

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Grain yield (Y_{grain})	7.413 kg/ha	9.400 kg/ha	5.330 kg/ha	2.900 kg/ha
Grain moisture(f_{grain})	15%	15%	14%	14%
Grain dry yield ($Y_{grain,dry}$)	6.301 kg/ha	7.990 kg/ha	4.583 kg/ha	2.494 kg/ha
Grain/stalk ratio(r_{stalk})	1,0	1,0	0,945	0,945
Quantity of stalk and hulk byproduct ($Y_{stalk,dry}$)	6.301 kg/ha	7.990 kg/ha	5.036 kg/ha	2.639 kg/ha

It is important to note that insofar as nitrogen fertilizer is produced using biogas, thenin this case based on the literature data, the full fossil fuel energy used during the entire process can be reduced from 35 MJ/kg to 2-4 MJ/ kg nitrogen, which is the energy required to transport the base product from which the biogas is derived (*Alghren et al.*, 2010). In our present closed model, this energy need of 2-4 MJ is also assumed to be met from energy having a biogas source.

RESULTS

Energy balance using traditional farming

The calculated energy balance of crop production using traditional farming is summarized in *Table 3*. It must be noted that in calculating the energy inputs, only the solar energy utilized directly by the crops is not considered, as this is received “for free” from nature.

Table 3: Maize and wheat energy balance for 1 ha

OUTPUT	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Amount of grain yield (15% moisture content) (Y_{grain})	7.413 kg/ha	9.400 kg/ha	5.330 kg/ha	2.900 kg/ha
Amount of maize stalk and cob ($Y_{stalk,dry}$)	6.301 kg/ha	7.990 kg/ha	5.036 kg/ha	2.639 kg/ha
Energy content of grain ($E_{grain,dry}$)[a]	**111.195 MJ**	141.000 MJ	**84.321 MJ**	45.878 MJ
Energy content of maize stalk and cob ($E_{stalk,dry}$)[b]	**97.666 MJ**	123.845 MJ	**80.237 MJ**	42.042 MJ
TOTAL OUTPUT ($E_{out,norm}$)	**208.861 MJ**	264.845 MJ	**164.558 MJ**	87.920 MJ
INPUTS				
Total energy input in the case of traditional method ($E_{inp,norm}$)	**21.124 MJ**	34.860 MJ	**14.406 MJ**	17.701 MJ
$E_{out,norm}/E_{inp,norm}$	**9,89**	7,60	**11,42**	4,97

[a] $E_{grain,dry} = Y_{grain} \times \left(1 - f_{grain}\right) \times e_{grain,dry}$, where energy content of grain is: $e_{grain,dry} = 15\ [MJ/kg]$ in case of maize and $e_{grain,dry} = 15{,}82\ [MJ/kg]$ in case of wheat

[b] $E_{stalk,dry} = Y_{stalk,dry} \times e_{stalk,dry}$, where energy content of stalk is: $e_{stalk,dry} = 15{,}5\ [MJ/kg]$ in case of maize and $e_{stalk,dry} = 15{,}93\ [MJ/kg]$ in case of wheat

[c] $E_{out,norm} = E_{stalk,dry} + E_{grain,dry}$

Biogas production from byproducts

Using total energy content of $H_{biogas} = 21{,}48\ [MJ/m^3]$ we can calculate the total biogas energy content that can be collected from the byproduct of 1 ha of crop (*Kacz K.,* 2008., *Chamber of Commerce and Industry Csongrád County,* 2011).

Table 4: Biogas yield from maize production byproduct

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Biogas yield for dry material in the case of stalks ($v_{biogas,stalk}$)	420 l/kg dry matter	420 l/ kg dry matter	250 l/kg dry matter	250 l/ kg dry matter
Biogas yield for maize stalk harvested from 1 ha (V_{biogas})[a]	2.646,4 m^3/ha	3.355,8 m^3/ha	1.259,2 m^3/ha	659,8 m^3/ha

[a] $V_{biogas} = Y_{stalk,dry} \times \frac{v_{biogas,stalk}}{1000}$

Fertilizer yield from biogas only

Table 5 illustrates how much biogas is needed when energy needs for manufacturing the nitrogen fertilizer necessary for 1 ha of maize or wheat is to be met using exclusively biogas input. The last two lines of the table illustrate the transport-related energy requirements of the biogas used to produce the fertilizer, which can also be met with a biogas-based energy supply.

Table 5: The energy input demand of N-fertilizer in the case of biogas

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Methane demand of 1 kg N-fertilizer[a] ($d_{CH4,fert}$)	0,981 m^3/kg			
Amount of biogas used for the production of 1 kg N-fertilizer[b] ($d_{biogas,fert}$)	1,636 m^3/kg			
The amount of N-fertilizer necessary for the production of 1 ha maize (m_{N-fert})	150 kg	155 kg	111 kg	68,4 kg
Biogas demand for N-fertilizer ($D_{biogas,fert}$) [c]	**245,4 m^3**	**253,6 m^3**	**181,6 m^3**	**111,9 m^3**
Input energy demand due to wrapping and transport because of biogas raw material [d] ($E_{transport}$)	**1.231,7 MJ/ha**	**1.657,1 MJ/ha**	**1.030,7 MJ/ha**	**1.141,1 MJ/ha**
- this supported by the use of biogas (taking into account 10% loss) ($D_{biogas,transport}$)[e]	**63,71 m^3/ha**	**85,72 m^3/ha**	**53,31 m^3/ha**	**59,02 m^3/ha**

[a] In the case of 35 MJ full natural gas energy input demand, of which the methane content is $f_{CH4,gas} = 97\%$ and its calorific value is $h_{gas} = 34{,}58 [MJ/m^3]$. *Tóth P. et al* (2011).

[b] The methane content of the produced biogas is $f_{CH4,biogas} = 60\%$, and the equation is the following

$$d_{biogas,fert} = \frac{d_{CH4,fert}}{f_{CH4,biogas}} = \frac{\frac{e_{N-fert}}{h_{gas}} \times f_{CH4,gas}}{f_{CH4,biogas}}$$

[c] $D_{biogas,fert} = d_{biogas,fert} \times m_{N-fert}$

[d] In our case I calculated using the *Gockler* (2013) equivalent for harvesting and transportation, which is in line with Hungarian conditions. According to this, the amount of gas oil needed for wrapping and bale-packaging is 14,4 kg/ha and 6 kg/tkm for 50 km of road transportation.

[e] $D_{biogas,transport} = \frac{\frac{E_{transport}}{h_{biogas}}}{\eta_{biogas}}$,

where the calorific value of biogas is $h_{biogas} = 21{,}48\ [MJ/m^3]$, and the efficiency of biogas usage is $\eta_{biogas} = 0{,}9$

Savings from gas transmission losses

In the case of production of nitrogen fertilizers using biogas only, the previously mentioned $r_{loss,gas} = 8\%$ natural gas transportation loss will not present. The chapter reviewing the literature showed that numerically 2,8 MJ of gas transportation will cause $v_{loss,gas} = 0{,}081 \frac{m^3}{kg\ N\ ferilizer}$ of losses, showing the expected size of natural gas shrinkage associated with the nitrogen fertilizer required for 1 ha of farming, and on this basis we can calculate the total losses from natural gas leaks associated with nitrogen fertilizer production for all of Hungarian maize and wheat production, as shown in *Table 6* (*Hungarian Central Statistical Agency*, 2017).

Table 6: CO_2 equivalent values of natural gas loss on account of N-fertilizer production

	Hungarian data	
	Maize	Wheat
Natural gas leakage by reason of 1 kg N-fertilizer production	0,081 m^3/kg	0,081 m^3/kg
N-fertilizer input in the case of 1 ha crop production	150 kg/ha	111 kg/ha
Natural gas loss because of 1 ha crop production	12,15 m^3/ha	8,99 m^3/ha
Total production area of Hungary in ha (average of the last 3 years)	1.116,37 ha	1.062,12 ha
Natural gas leakage on account of N-fertilizer usage for total crop production in Hungary	13.559.150 m^3	9.546.189 m^3
Leaked CH_4 greenhouse gas	13.152.375 m^3	9.259.803 m^3
weight of this	9.417.101 kg	6.630.019 kg
CO_2 equivalent of this	**235.427.518 kg CO_2 eqv.**	**165.750.475 kg CO_2 eqv.**
Leaked CO_2 greenhouse gas	71.457 m^3	50.308 m^3
weight of this	**141.270 kg CO_2 eqv.**	**99.460 kg CO_2 eqv**

Input energy needs in the case of a fully biogas-based energy supply

In the case of the full production process we have separated the nitrogenproduction and all other energy needs, since we separately treated the fertilizer production process using the Haber-Bosch process, assuming use of biogas for this purpose. On this basis for maize the Hungarian case showed $E_{inp,norm} = 21.124\ [MJ/ha]$. If we deduct the nitrogen-based fertilizer production from this value, then the remaining need above this amount is $E_{inp,cultivation} = 15.454\ [MJ/ha]$. We performed the same calculation for wheat, and for both maize and wheat calculated the USA figures. To this we must then add the baling and transport energy needs associated with 100% biogas-based fertilizer production, as well as the biogas required to produce the fertilizer itself. The results are shown in *Table 7*. A conversion loss of 10% was calculated for all biogas utilization processes with the exception of fertilizer production using the Haber-Boschprocess.

Table 7: Input values of the production of 1 ha grain using their own byproducts based on 100% biogas input

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
Energy inputs with the exception of N-fertilizer production ($E_{inp,cultivation}$)	**15.454,4 MJ/ha**	29.001 MJ/ha	10.210 MJ/ha	15.115 MJ/ha
- amount of biogas necessary for this ($D_{biogas,cultivation}$)	**799,42 m^3/ha**	1.500,15 m^3/ha	528,14 m^3/ha	781,86 m^3/ha
The amount of maizestalk necessary for the production of fertilizer ($D_{biogas,fert}$)	**245,45 m^3/ha**	253,63 m^3/ha	181,6 m^3/ha	111,9 m^3/ha
The amount of maizestalk necessary for the energy demand of wrapping and transport ($D_{biogas,transport}$)	**63,71 m^3/ha**	85,72 m^3/ha	53,31 m^3/ha	59,02 m^3/ha
The full biogas demand in the case of a 100% biogas based production process ($D_{biogas,production}$)	**1.108,58 m^3/ha**	**1.839,50 m^3/ha**	**763,08m^3/ha**	**952,81 m^3/ha**
The amount of maize stalk necessary for the production of the full biogas amount ($M_{stalk,demand}$)[a]	**2.639,5 kg**	**4.379,8 kg**	**1.816,9kg**	**2.268,6 kg**
Its energy content) ($E_{stalk,demand}$)[b]	**40.912** MJ	67.886 MJ	**28.942** MJ	26.139MJ
How many hectares' full input can the total amount of maizestalk produce on 1 ha supply?	**2,39 ha**	**1,82 ha**	**1,65 ha**	**0,69 ha**

[a] $M_{stalk,demand} = \frac{D_{biogas,production}}{\frac{v_{biogas,stalk}}{1000}}$

[b] $E_{stalk,demand} = M_{stalk,demand} \times e_{stalk,dry}$

Energy ratios in the case of 100% biogas-based production

In the case of production within a closed system, in which 100% of the energy input is produced using biogas from the system's own byproducts, we do not have to account for the losses that would occur from natural gas transportation used for traditional nitrogen fertilizer production. The collection and transport of the raw materials to be used for biogas production (baling and transport processes) do, however, need to be accounted for, as an additional input factor.

When calculating energy output, the amount of biomass byproduct used for producing the biogas should be subtracted from the full biomass output, as this is will be removed from the system.

On the basis of averages in the technical literature, the output/input energy balance of biogas production itself is 2,56:1, meaning every MJ of energy input is sufficient for production of 2,56 MJ of biogas output. Thus the total necessary biogas fuel input required is 1/2,56 in order to maintain the system.

Table 8: The energy demand of maize production in the case of 100% biogas sourced production

	Maize		Wheat	
	Hungarian data	USA data	Hungarian data	USA data
ENERGY OUTPUTS				
Total outputs ($\boldsymbol{E_{out,bio}}$)[a]	**170.301 MJ/ha**	**264.845 MJ/ha**	**137.637 MJ/ha**	**54.019 MJ/ha**
ENERGY INPUTS				
Full biogas demand for the whole production process ($D_{biogas,production}$)	1.108,58 m^3/ha	1.839,50 m^3/ha	**763.08 m^3/ha**	**952.81 m^3/ha**
Total calorific value of biogas ($H_{biogas,production}$)[b]	23.812,4MJ/ha	39.512,4 MJ/ha	16.391,0 MJ/ha	20.466,4 MJ/ha
delivered input energy for this biogas ($\boldsymbol{E_{input,biogas\ process}}$)[c]	**9.301,72MJ/ha**	**17.561,1MJ/ha**	**6.402,7 MJ/ha**	**9.096,2 MJ/ha**
$\boldsymbol{E_{out,bio} / E_{input,biogas\ process}}$	**18,31**	**11,39**	**21,50**	**5,94**

[a] $E_{out,bio} = E_{out,norm} - E_{stalk,demand}$

[a] $H_{biogas,production} = D_{biogas,production} \times h_{biogas}$

[a] $E_{input,biogas\ process} = \frac{H_{biogas,production}}{2,56}$

CONCLUSIONS

Based on the results of the model derived in the study, the results should be broken down in two ways. On the one hand from an energy standpoint (energy balance increase, energy balance decrease), and on the other hand the results can be evaluated from an ecological standpoint (the environmental damage of leaks during natural gas transmission associated with nitrogen fertilizer production, and its reduction).

Energy changes in the case of maize production

In the case of maize production, both Hungarian and USA modes of production could achieve considerably higher energy levels in the case of a closed system. In the case of production in Hungary, the full energy balance of the system would increase from 9,89 to 18,31, while evaluation of the USA data shows that there the energy rate would increase from 7,60 to 11,34. The maize produced on 1 ha is sufficient for meeting the total energy requirements of 2,3 ha in the Hungarian case and 1,8 ha in the case of the USA.

If we consider data from more years, then energy balance of maize production trends about 12-20 in the case of a closed production system, depending on the actual yield and the method of the production.

This means that investigation of the practicality of a closed system, as well as examination of the ways of using byproducts for optimizing the C:N ratio of biogas production, is certainly worth further investigation.

Energy changes in the case of wheat production

In the case of wheat production, the results are more varied. On the basis of Hungarian data, it can be stated that a clear increase in energy ratio can be achieved, from 11,42 to 21,50. However, on the basis of the USA data, the energy ratio can "only" increase from 4,97 to 5,93, where the whole of the input is provided by biogas produced from wheat straw, which is a non-negligible increase, though there remains one important consideration. While the quantity of wheat produced on 1 ha in the Hungarian case is sufficient for 1,65 ha, in case of the USA it is sufficient for the total energy requirements of only 0,69 ha of wheat production. In other words, using the USA production mode, insufficient wheat straw is generated on 1 ha to meet the total energy need of 1 ha of production, instead it is only able to meet 69% of the energy requirement. An underlying assumption of our model is that evaluation of the closed-system production makes sense only if the yield (and quantity of byproduct) is sufficient to meet at least its own energy requirement. This depends on environmental conditions, and due to differing farming methods it will not be possible in the case of every plant in all parts of the world.

This problem could be solved in the present instance by utilizing byproducts from different sectors (e.g. maize production) to compensate for missing byproducts, from sectors that have much more byproducts than their own requirements. This assumes an extended model and can be the basis of further research.

Another important aspect is that the model does not account for utilization of the sludge or fermentation liquid remaining after production of biogas – for example, by spraying it on arable land. This would increase energy requirement (transport, machinery) however,it also increases energy yield (increased biomass yield). On the basis of Hungarian experiments, dilute slurry poured into alfalfa resulted in a 50% biomass increase (6 instead of 4 reaping possibilities: *Tomócsik, A. et al.*, 2007 and *Petis, M.*, 2017., oral statement).

Ecological aspect

In the case of purely biogas-based production, the amount of fossil fuel can be saved for which we instead use biogas-based energy. Besides the obvious potential for savings, it is vital to emphasize also the potential savings from leaked natural gas which would have occurred due to nitrogen fertilizer production. The extent of this has not been specifically addressed to date in the literature. Results of natural gas leakage, shown in *Table 6.*, and their CO_2 values mean a huge amount of greenhouse gas emissions, which could be saved.

In the case of Hungary, leakage loss due to the N-fertilizer production associated with the maize and wheat production sector accounts for 0,74% of the country's CO_2 and CH_4 emissions (on CO_2 equivalent basis), which does not seem to be much. However, we know that most of the leakage loss is methane (97%) and only a low part is CO_2 (0,56%). If we only examine Hungary's present methane emissions, the leakage loss accounts for 5,26% of the country's total methane emissions (based on data from the *Hungarian Central Statistical Office*, 2017).

It is interesting to note that in the year 2016, 650 thousand tons of CO_2 equivalent methane were dropped in the air due to leakage losses. Based on our calculations, only 401,2 thousand t CO_2 equivalent of methane is emitted in the air for the Hungarian wheat and maize production (which of course does not apply only to Hungary). There is no information about what part of this emission is allocated to Hungary's territory. The literature is also incomplete regarding how calculated the gas transport losses have been calculated in the national economic statistics reports.

Research of this would require a separate study, because of its overriding importance.

Bevezetés a fosszilis energiahordozó mentes gabonatermesztésbe

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Mosonmagyaróvár

ÖSSZEFOGLALÁS

A mezőgazdaság kiemelkedően fontos iparág az emberiség számára. Ez az az ágazat, amely a történelem során végigkísér bennünket, hiszen az élethez nélkülözhetetlenül szükséges termékeket állít elő. Ezért kiemelkedően fontos, hogy energiafelhasználás szempontjából ne csak egy adott pillanatban, hanem hosszú távon is fenntartható legyen a rendszer.

A gabonatermesztés ágazata mind gazdasági mind területi szempontból elsődleges a mezőgazdasági területeket figyelembe véve. Magyarországon 2017.-ben a szántónak minősített területek 56%-án gabonát termeltek, melynek túlnyomó részét az őszi búza és a kukorica tette ki, összesen csaknem 2 millió ha vetésterülettel. Világviszonylatban is óriási súlya van ennek a két gabonának. Nagy jelentőségük miatt e két gabona termelésének energiamérlegét vizsgáltuk.

A jelenleg alkalmazott nyílt energetikai rendszerhez képest vizsgálatra került, hogy zárt rendszer esetén hogyan alakulna a rendszer energiamérlege. A zárt rendszer kizárólag a melléktermékként megmaradó szalma illetve kukoricaszársegítségével előállított biogázra támaszkodik, mint input energiára.Ez közvetlen módon használható műtrágya előállításra és hajtóanyagként, vagy közvetett módon hőenergia vagy villamos energia termelésre. Kiszámítható, hogy egy hektár termőföldön keletkező melléktermék segítségével fedezhetőlenne-e a termelés teljes energiaigénye, illetve hogyan változna a termelés energiamérlege a jelenlegihez képest.

A vizsgálat során kiderült, hogy a kukorica esetében a legnagyobb energiaigényt a N alapú műtrágya termelése követelt (több, mint a teljes energiaigény negyede). A búza esetében részben a növény alacsonyabb N igénye, részben a technológia miatt a bevitt összes energiamennyiség kevesebb, mint a kukoricánál. A búzaszalmából nyerhető biogáz mennyisége viszont kevesebb, mint a kukorica esetében.

A tanulmány a maradvány termékek energetikai felhasználását kizárólag biogáz technológiával feltételezi – ez decentralizált módon is megvalósítható.

Kulcsszavak: energia mérleg, biogáz, biogáz alapú energiatermelés, kukoricatermelés, őszi búza termelés

ACKNOWLEDGEMENTS

I would like to express my special thanks to Mihály Petis, who supported us with oral and written datas about biogas production in their biogas plant of Bátortrade Ltd. in Nyírbátor, Hungary.

This research was supported by VKSZ-12-1-2013-0034 "Agricultural Climate" Competitiveness and Excellence Contract.

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