OPTIMIZATION OF THE PRODUCTION STRUCTURE OF FIELD ENERGY CROPS

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Abstact: *In our paper we have dealt with the biomass-based energy production during the agricultural production, since the sustainable energy management is one of the most actual issues. In our paper we have dealt with the biomass-based energy production during the agricultural production, since the sustainable energy management is one of the most actual issues. In our research we wanted to know how much renewable energy could be produced on a field of 1800 hectares with five plants (silage maize, Lucerne, wheat, maize, sunflower). Data of the energy content were collected from literature, all other data were collected from a company in the Northern Great Plain Region with 1800 hectares and the information from the Institute of Agricultural Engineering (IAE). Besides, we analysed how much income could be reached and for what the produced energy could be used, what demand it could meet by replacing fossil energy sources having high environmental pressure. Crop production technologies applied in the model were set up by the practical experiences of a real agricultural company. Working operations were set on a monthly basis with the assignment of prime mover – machinery relations. The material needs of the working operations were also set (fertilizers, pesticides, sowings, twines, silage foil) where it was needed. To answer our research question two model variants were elaborated. In the first model variant the five crops were competed by the maximum energy content, and in the second variant by the maximum gross margin. Production optimization was done for 1800 hectares. We supposed that 100% of the plant products are marketed (animal farms are not considered), and in the model only raw material production is done (further processing of plant products for energy purposes are not part of this analysis). Besides, we supposed that these five plants will be used as: by-products (wheat straw, maize stem, sunflower stem) and Lucerne hay by direct combustion; bioethanol from wheat and maize grain; biodiesel from sunflower grain; biogas from silage maize.*

Keywords: optimalization, *the biomass-based energy production; renewable energy,* linear programming

JEL Classification: N70; Q42; P18; P48

Material and methods

In this paper the optimization of the production structure for five field energy crops (silage maize, lucerne, wheat, maize, and sunflower) was done by linear programming.

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We supposed that 100% of the plant products are marketed, and in the model only raw material production is done. Besides, we supposed that these five plants will be used as: 1. by-products (wheat straw, maize stem, sunflower stem) and Lucerne hay by direct combustion; 2. bioethanol from wheat and maize grain; 3. biodiesel from sunflower grain; 4. biogas from silage maize.

In the first model variant the objective function coefficient values were the energy yields of crops per one hectare, in the second model variant the values were the value of production, direct and variable cost from which contribution and gross margin were calculated.

For the calculations the average energy content of the crops, yields of the main and by-products, production technologies, the demand and cost of machine hours, marketing prices, the amount of subsidies, and the data for machine park were needed.

Results

Crop production technologies applied in the model were set up by the practical experiences of a real agricultural company. Working operations were set on a monthly basis with the assignment of prime mover – machinery relations. The material needs of the working operations were also set (fertilizers, pesticides, sowings, twines, silage foil) where it was needed.

Determination of the energy yields for crops applied in the model

Energetically the by-products (maize and sunflower stem, wheat straw) and Lucerne hay will be used by direct combustion. Bioethanol will be produced from the produced maize and wheat grain, biodiesel from sunflower grain, and biogas from silage maize.

For the estimation of energy yields we needed the planned average yields, the amount of by-products, the rate of derived products from the main products (bioethanol, biodiesel, biogas), and the energy content of by- and derived products.

Determination of the yields for by-products

For the calculation of the yields for by-products the following data were taken into account. From 1 ton of wheat grain we get 0,5 ton of straw, from 1 ton of maize grain we get 0,8 ton maize stem, while from 1 ton of sunflower grain we get 2 tons of sunflower stem. If we know these data and the average yield of the main products we can calculate the amount of by-products per hectare.

Average yields of the main products presented were calculated by the last 3 years data of the examined company. Thus, in the model the average yield of silage maize is 42 tons, Lucerne hay's is 7.3 tons, wheat's is 4.6 tons, maize's is 8.3 tons and the sunflower's is 3.1 tons. Specific yields per hectare of the three by-products were calculated by the average yields and the rate of main and by-products, so the calculated yield of wheat straw, maize and sunflower stem is 2.3, 6.7 and 6.2 tons per hectare in order.

Calculation of the yields of bioethanol, biodiesel and biogas

Below you can see the estimation of yields of bioethanol, biodiesel and biogas from the grains of wheat, maize, sunflower and silage maize.

1 kg maize grain we can get 0.33-0.35 litre absolute alcohol (almost the strength of 100% alcohol) (0.34 litre on average), from 1 kg wheat grain 0.35-0.36 litre (0.355 litre on average). These quantities in litre were calculated to kg by the density data of 0.79 kg/dm^3, because the energy content of ethanol is given in quantity not in volume. Based on the given numbers from 1 kg maize grain we get 0.2866 kg, from 1 kg wheat grain we get 0.2805 kg absolute alcohol, so it means that 286.6 kg and 280.5 kg ethanol per tons.

Multiplying these data with the average yields of maize (8.3 tons) and wheat (4.6 tons), we got to know that the quantity of bioethanol per hectares is 2238.3 kg from maize ad 1299.4 kg from wheat.

We can conclude that based on the calculations we can produce 1.7 times more bioethanol from maize.

The amount of sunflower oil form 1 ton of sunflower grain is 430 litres, which means 395.6 kg derivable oil per tons. This number – similar to maize and wheat – was multiplied with the average yield of 3.1 tons and the result was that we could get 1226.4 kg oil yield per hectares.

Biogas yield of silage maize was determined by the calculations of *Kőrösi, 2008* for a possible biogas plant. In the planned virtual biogas plan 15 thousand tons of silage maize was fermented (beside other materials), which total biogas yield was 2457 thousand m^3 with 1277.6 thousand m^3 methane content. The rate of methane in the biogas from silage maize was 52%. (It is needed to present the methane content, because the other 48% is not combustible carbon dioxide.) So we determined the biogas yield of 1 ton silage maize, which is 163.8 m^3 with 85.17 m^3 methane content. This value was multiplied with the average yield of silage maize (42 tons), therefore we got that the quantity of biogas will be 6879.6 m^3 from silage maize.

Calculation of energy yields

In the previous chapters we estimated the specific yields of by-products and derived products. To determine the energy yields of the crops we need the calorific values of the products, which is presented in *Table 1*.

Table 11. Average energy content of some by-products

Name	**Energy content (MJ/kg; MJ/m^{3*})**	**Name**	**Energy content (MJ/kg; MJ/m^{3*})**
Bio ethanol	26.8	**Straw**	13.5
Biodiesel (sunflower)	39.8	**Lucerne hay**	14.4
Maize stem	13.0	**Biogas (from silage maize)**	17.4
Sunflower stem	11.5		

* MJ/m^3 is used only for biogas

Source: Chlepkó – Kőszegi, 2008; Barótfi, 1993; Kőrösi, 2008

The energy content of biogas from silage maize was calculated by us. The energy content of biogas changes depending on the methane content, since only the methane component can combust. The energy content of this gas is 9.28 kWh/m^3 which is 33.41 MJ/m^3 according to *Chlepkó-Kőszegi, 2008*. Since in the model the biogas has 52% methane content, the calorific value is 52% of 33.41 MJ/m^3, so it is 17.4 MJ/m^3.

Based on these date the energy yield per hectare was determined (*Table 2.*). Energy yields of the crops are calculated by the multiplication of the product yields in kg and the specific energy yields. So, the highest energy content has the maize (146.7 GJ/ha), which is followed by sunflower, silage maize and Lucerne (120.1 GJ/ha, 119.5 GJ/ha and 104.6 GJ/ha). Wheat has the lowest energy (66.1 GJ/ha) which is lower than half of the energy content of maize.

Table 2. Energy yields of crops per hectare

Name		**Yield (kg/ha; m^3/ha*)**	**Energy content (MJ/kg; MJ/m^{3*})**	**Total energy yield (GJ/ha)**	
Silage maize	**Biogas**	6 879.6	17.4	119.5	**119.5**
Lucerne	**Lucerne hay**	7 266.7	14.4	104.6	**104.6**
Wheat	**Bioethanol**	1 299.4	26.8	34.8	**66.1**
	Straw	2 316.7	13.5	31.3	
Maize	**Bioethanol**	2 238.3	26.8	60.0	**146.7**
	Maize stem	6 666.7	13.0	86.7	
Sun-flower	**Biodiesel**	1 226.4	39.8	48.8	**120.1**
	Sunflower stem	6 200.0	11.5	71.3	

* m^3/ha and MJ/m^3 are used only for biogas

Source: Own calculation

Calculations of the direct costs and gross margins of the applied crops in the model

Direct costs were divided into four expenditures: material costs, personnel costs, machinery costs (within this material, personal, amortization and other costs) and other costs.

The following costs were grouped into the expenditures: Material costs (costs of seed, fertilizer, pesticides, twine, silage folia); Personnel costs (the applied labour costs); Machinery costs (costs of machine and building); Material costs (costs of fuel, lubricants, costs of repair, energy costs of cleaning and drying); Personnel costs (salary and benefits for drivers and repairmen); Amortization (cost of amortization for prime movers, towed machinery and buildings); Other costs (other costs like taxes of machines, insurance, etc.); Other costs (insurance costs, rent of land, and other costs).

The material and other costs were calculated by the examined company considering the marketing costs, land rent and insurance costs.

Machinery costs were determined by the examined company's costs and the lease work costs for 2015 given by the Institute of Agricultural Engineering. These data are the costs for in-storing and out-storing, storage, cleaning, drying, and the other costs were taken into account by the data from IAE. The working operation costs of IAE contain the entrepreneurial profit as well, so this had to be reduced. In our calculations we used 30% profit rate, so 70% was used as cost price.

Machinery costs by expenditures were calculated backwards to make the calculations easier. From the cost of the company and IAE we could calculate the total machinery cost. Personnel costs and amortization rate were determined by the data of the examined company. Other costs were set to 10.1%. So the material cost was calculated by the difference of total machinery cost and these three costs.

The rate of machinery service costs is the following (in the rate of total machinery cost): Material costs: 26.3%; Personnel costs: 21.0%; Amortization costs: 42.6%; Other costs: 10.1%.

Direct costs of silage maize is 285 587 HUF, of Lucerne is 155 226 HUF, 257 259 HUF for wheat, 302 089 HUF for maize and 214 913 HUF for sunflower. It can be seen that maize has the highest direct costs, which is followed by silage maize, wheat, sunflower and Lucerne. The reason for that is the higher cleaning and storage costs.

After determining the direct costs we calculated the contribution (gross margin).

Contribution is a category in accountancy (which is the gross result of sales). It can be calculated by the difference of production value and direct costs, which gives a margin for the overheads and the profit. It measures the income generating ability on the level of product not the company, since it does not take the overheads into consideration, but the direct costs appeared during production.

Gross margin is the difference of production value and variable costs. Gross margin measures how the changes in volume contribute to the income. It can be that we know a product's contribution, but the increase or decrease of this product will not increase or decrease the income of the company by the contribution of the product, but the value of gross margin, since in the calculations we reduced the variable costs and the overheads as well (which also occur when we do not produce anything). It is the reason why we optimize the gross margin of any activity and not the contribution – just like in the second model variant.

What we consider volume, fix and variable costs depends on the decision problem. At the optimization of the production structure we want to know which crop to plant on how many hectares to reach the maximum income.

In this decision problem we consider variable (relevant) cost every cost (material, other costs, machinery costs), which appears during the crop production. Among these the cost of repairing and lubricants are digressively variable costs. These costs should be divided into reduced fix costs and reduced proportionally variable cost theoretically. Since we do not know the reacting rate of these costs, we supposed for the simplicity that these costs change proportionately.

The above not mentioned expenditures (land rent and other costs within other direct costs, personnel costs within machinery costs, amortization and other costs) are fix (not relevant) costs. Land rent agreements are contracted for years in advance, so these appear without production as well, the staff must also be paid, amortization and taxes of prime movers also have to be paid, etc.

Contribution and gross margin values were calculated by these principles for one hectare. Production value was counted by the revenue and the subsidies. Revenues were set by the last three years' data for yields and prices on average. Where the price was not k, the internal prices were used. The amount of subsidies is 70 880 HUF/ha for every crop.

The value for gross margin for silage maize is 294 591 HUF, for Lucerne it is 164 742 HUF, for wheat it is 185 067 HUF, for maize it is 326 244 HUF and for the sunflower it is 194 560 HUF.

The linear programming model

Production optimization of the five field crops was executed by two aspects. In the first model variant we were looking for the production structure where maximum energy yield could be reached, in the second model variant the maximum income.

In the two models the following constraints were applied: constraints for crop rotation, capacity constraints for prime movers' hours. We supposed that the financing of the operation is ensured, so financial constraints were not applied in the models.

Crop rotation constraints were determined by the biological needs of the crops. Maize can be produced in monoculture for long years, but after 4-5 years significant yield decline can be seen because of the pests and weeds. An upper limit of 900 hectares was introduced for the joint area of maize and silage maize. If both crops are planted on 900 hectares every year, it can be solved that they will be placed on the same field in 2 years. In case of wheat the general principle is that it should be planted maximum three years in a row (Szabó et al., 1992). Since the sunflower is one of the most susceptible plants to diseases, it cannot be planted on the same field within 5 years, or it can be even 6-7 years in serious cases (Antal, 1992). Therefore, the area of sunflower was constrained to one-fifth of the total area, 360 hectares. Lucerne is produced on the field for 4 years. Nevertheless, field constraint was set into the model. The reason for that is if Lucerne is planted to a big proportion of the total area, the machine park would remain unused which would make the production inflexible. Therefore, there was a 450-hectare constraint for lucerne.

As far as constraints for machine hours are concerned there were tractors with different performance (MTZ 82 /5 pcs/, New Holland TM 155 /4 pcs/ and Rába 250 /4 pcs/), one harvester (New Holland CX 6080), one straw-cutter (New Holland FX 40), and 3 Caterpillar TH 330 mechanical loaders.

Machinery demand in hours for each crop was determined according to the working operations monthly by prime movers, which was given by the company. We supposed that a given working operation is done by the same prime mover.

Upper limits of prime movers were set for 10 hours in a shift. So monthly the maximum number of machinery hours: *b= number of days/month * number of prime movers * 10*.

In the first model variant we were looking for the maximum energy yield where $119{,}5x1 + 104{,}6x2 + 66{,}1x3 + 146{,}7x4 + 120{,}1x5 \rightarrow max!$ In the second model variant the objective is the maximum gross margin where $294591{,}5x1 + 164742{,}4x2 + 185066{,}9x3 + 326243{,}9x4 + 195560{,}3x5 \rightarrow max!$

The first model variant

The calculated maximum energy yield of the model is 202 885.4 GJ which can be reached by 342 ha of silage maize, 450 ha hectares of lucerne, 388 ha wheat, 558 ha maize and 62 ha sunflower, and the total area of 1800 hectares is used. None of the five crops has shadow price, since all of them got into the production structure.

The shadow price of the activities shows that with how much the specific energy yield should be increased to get into the production structure without changing the objective function's value (202 885.4 GJ). Allowable increase and decrease show the value of fluctuation without changing the optimal production structure. It is presented in *Table 3*.

Table 3. Upper and lower limits of the objective function coefficients in the first model variant

Name	**Solution (ha)**	**Upper limit (GJ/ha)**	**Objective function coefficient (GJ/ha)**	**Lower limit (GJ/ha)**
Silage maize	342	203.48	119.5	92.64
Lucerne hay	450	∞	104.6	55.08
Wheat	388	92.96	66.1	- 17.88
Maize	558	173.51	146.7	130.43
Sunflower	62	136.34	120.1	93.25

Source: Own calculation

The upper limit of objective function coefficients is the sum of the objective function's value and the allowable increase, the lower limit is the difference of objective function's value and the allowable decrease. The analysis of these values are extremely important. The calculated energy yields are greatly affected by the average yields in the optimization. The average yields highly depend on the weather, which affect the energy yields as well. In fact, the wider interval the objective function coefficient can fluctuate, the safer the optimal production structure is. Shadow prices of the model's resources are summarized in *Table 4*.

Resources have shadow prices it they are fully used, so they are bottlenecks. In the model these resources are the following: New Holland TM 155 and New Holland CX 6080 harvester in October, the total area, silage maize and maize and the area of lucerne. In the cases of the prime movers the shadow price is 21 and 123.1 GJ, in the cases of areas they are 55.1; 20.1 and 49.6 GJ.

Table 4. Shadow prices of the resources in the first model variant

Name	Use	Shadow price (GJ)	Allowable increase	Allowable decrease
NH TM 155 X. (m. hour)	1 200	21.0	355.6	64.4
NH CX 6080 X. (m. hour)	310	123.1	116.4	19.7
Total area (ha)	1 800	55.1	9.7	275.1
Silage maize + Maize (ha)	900	20.1	50.0	240.4
Lucerne (ha)	450	49.6	118.1	9.7

Source: Own calculation

In *Table 5.* the above mentioned production structure with the maximum energy yield is presented.

Table 5. Combination of the maximum achievable energy yield

Name	Energy (GJ)	Distribution (%)
Bioethanol	46 983.3	23.16
Biodiesel	3 027.0	1.49
Biogas	40 872.7	20.15
By-product	112 002.5	55.20
TOTAL	**202 885.4**	**100.00**

Source: Own calculation

By-products and lucerne hay give the highest rate 55% (112 002.5 GJ) of the total energy (202 885.4 GJ). After that comes the bioethanol which can be used in transportation (46 983.3 GJ, 23%) then biogas for heating purposes with 40 872.7 GJ (20%). The smallest part has the biodiesel which can be produced from sunflower. It is 3 027.0 GJ (2%).

The calculated energy of 202 885.4 GJ can be realized with 440 858 thousand HUF gross margin. The distribution if it is shown in *Table 6*.

Table 6. The amount of gross margin at maximal energy yield

Name	Gross margin (thousand HUF)	Distribution (%)
Silage maize	100 755.0	22.85
Lucerne	74 134.1	16.82
Wheat	71 803.0	16.29
Maize	182 038.8	41.29
Sunflower	12 127.9	2.75
TOTAL	**440 858.8**	**100.00**

Source: Own calculation

In the production structure's gross margin giving the maximum energy yield the maize shares 182 038.8 thousand HUF (41.29%), which is followed by silage maize (100 755.0 thousand HUF, 22.85%). The amount of gross margin of lucerne and wheat is almost the same: 74 134.1 thousand HUF (16.82%) and 71 803.0 thousand HUF (16.29%). The smallest share has the sunflower with 12 127.9 thousand HUF (2.75%).

The second model variant

The maximum gross margin of the model is 441 974.3 thousand HUF, which can be reached by 291 hectares of silage maize, 448 hectares of lucerne, 441 hectares of wheat, 609 hectares of maize and 11 ha sunflower, so the total area of 1800 ha is used. Similar to the first variant of the model, none of the crops has shadow price (*Table 7.*).

Bottlenecks of the model variant is the total area, the joint area of silage maize and maize, Rába 250 tractor in September, New Holland CX 6080 harvester in October (*Table 8.*). Increasing or decreasing the capacities of the resources by one unit modifies the maximum gross margin with the sum amount of shadow prices.

Table 7. Upper and lower limits of the objective function coefficients in the second model variant

Name	Solution (ha)	Upper limit (thousand HUF/ha)	Objective function coefficient (thousand HUF/ha)	Lower limit (thousand HUF/ha)
Silage maize	291	312.4	294.6	-∞
Lucerne	448	191.9	164.7	58.1
Wheat	441	∞	185.1	164.5
Maize	609	∞	326.2	308.5
Sunflower	11	213.3	195.6	-∞

Source: Own calculation

Table 8. Shadow prices of resources in the second model variant

Name	Use	Shadow price (thousand HUF)	Allowable increase	Allowable decrease
Total area (ha)	1800	142.4	2.3	8.8
Silage maize + Maize (ha)	900	130.7	11.1	348.9
Rába 250 IX. (hour)	1200	25.8	19.3	1.9
NH CX 6080 X. (hour)	310	63.3	145.5	19.6
MTZ 80 VII. (hour)	1550	11.2	17.5	74.2

Source: Own calculation

Maize gives the highest rate 44.95% (198 659 thousand HUF) of the maximum gross margin, which is followed by silage maize (85 747.3 thousand HUF; 19.40%). In cases of lucerne and wheat the amount of gross margin is 73 830.1 thousand

HUF (16.70%) and 81 572.6 thousand HUF (18.46%). The smallest share has the sunflower with 2 165.3 thousand HUF (0.49%).

The maximal gross margin of 441 974.3 thousand HUF can be realized by the energy yield of 201 445.9 GJ.

By-products and lucerne hay has the highest rate of 56.71% (114 243.3 GJ) of the total energy (201 445.9 GJ). After that comes the bioethanol which can be used in transportation (51 877.6 GJ, 25.75%) then biogas for heating purposes with 34 784.6 GJ (17.27%).

The smallest part has the biodiesel which can be produced from sunflower. It is 540.4 GJ (0.27%).

Conclusions

According to the suppositions considered in the production structure's optimization among the 5 crops the maize has highest energy yield with 146.8 GJ, which is followed by the sunflower's 120.1 GJ. The calculated energy yield of silage maize is 119.5 GJ, the lucerne's is 104.6 GJ. The wheat has the lowest energy yield (66.1 GJ/ha). Since the bioethanol is the product of two plants (maize and wheat), it was important to compare the bioethanol yields of these crops. Compared with the wheat, we can produce 1.7 times more bioethanol from maize. As the quantity of alcohol from both plants is almost the same, the difference comes from the average yields (8.3 t/ha from maize, 4.6 t/ha from wheat). In the first model variant the maximum energy yield is 202 885.4 GJ on 1800 ha which can be realized with 440 858.82 thousand HUF gross margin. Total energy yield of the second model variant is 201 445.9 GJ with 441 974.3 thousand HUF. It can be seen that there is not much difference between the two models: the absolute differences are 1 439.5 GJ and 1 115.48 thousand HUF. Based on the results, the question occurs for what this maximum 202 885.4 GJ energy yield can be used. Energy demand of a house of 100 m^2 with medium insulation is approximately 136 GJ (*Lakner, 2002*). So the energy of 112 002.5 GJ produced from by-products (maize, sunflower stem, wheat straw) and lucerne hay with direct combustion is enough for the energy demand of 823 above-mentioned houses. If we suppose that in these houses 4 people live, we can conclude that 112 002.5 GJ energy meets the energy demand of 3 292 people, which means a bigger village. The quantity of biogas from silage maize (40 872.7 GJ) would increase the number of houses by 300, so approximately by 1200 people. The energy content of gasoline is 35.15 MJ/litre. Total energy content from bioethanol in the model calculations is 46 983.3 GJ. This energy is equal with the energy content of 1 336 651 litres gasoline. If we count with a normal diesel car of 150 horsepower with an average consumption of 5l/100 km, this energy is enough to drive 26 733 thousand km. If we suppose that one car goes 15 thousand km a year, it can be concluded that 46 983.3 GJ energy meets the energy demand of 1782 cars with the previously mentioned parameters.

Total energy content of the biodiesel calculated by the model from sunflower is 3 027.0 GJ. It is equal with the energy of 86 115 litres gasoline. This energy can increase the number of kilometres by 1772.3 thousand kilometres and 118 cars at average use.

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