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Article

The Effects of Material's Transport on Various Steps of Production System on Energetic Efficiency of Biodiesel Production

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Abstract: Based on rapeseed plantation biodiesel production system requires transportation of goods, like raw materials, machines and tools, and products between various conversion stages of agricultural as well as industrial subsystems. Each transportation step requires consumption of some energy. This consumption, decreases the net amount of energy delivered out of the biofuel production system, and consequently decreases energetic efficiency of the system. The present work deals with computer modelling of the influence of energy consumed on those transport routes on the energetic efficiency of production system. The effects caused by variation of several parameters like fuel consumption and load capacity of transportation means, size of plantation, distribution and sizes of individual fields, distances between fields, as well as plantation yield, and finally the distance between plantation and the industrial facility are studied using the numerical model developed.

Keywords: biodiesel, energetic efficiency, modelling, transport, sustainability

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1. Introduction

The relations of humans with the nature are the form of the husbanding whose main task is the logging of supplies and satisfaction of needs. The mankind from always aimed to the logging of natural supplies from the ground, water and air. The initial human activity did not make the large threat for the environment. Together with the growth of the population, the problems relating to the shrinking of natural supplies arise, which to more and more degree make up the threats for the regeneration of individual ecosystems.

The pollution of the environment, the exhausting of natural supplies, the growth of wastes disturb the equilibrium of the natural environment. Growing violation of this equilibrium makes increasing problem to the present world. The majority of areas feels dangerous threats being the consequences of pollution of waters, soil or air, which may lead to contamination of products.

The development of technology, from one side contributes to the reduction of human's dependence on the nature, but on the other hand, leads to even stronger response form the environment. Dynamism of technological progress results in the unbalanced economic growth, and leads to the disproportion of development in the local as well in the global scale. The development of the production should keep up not only for the demographic growth, but also the natural environment has to be taken into account. The humanity must realize that the environment should be kept in the best state for the future generations.

The durability of the development has the essential meaning for the sustainable development. The sustainability requires, in turn, that the proportion between the natural and human capital is preserved as well as that during exploitation of those capitals, the irreversibility of processes is taken into account.

The natural environment is a complex structure being characterized by its own internal dynamics dependent on the flows of the streams of mass and energy. To some limit it is able to bear burdens connected with the man's economic activity, and in certain degree to neutralize negative results through natural biochemical and geological processes. Crossing of this limit might, however, lead to the degradation of the ecosystem itself. The observations, and investigations of the relationships between the economy and the environment, are indispensable because they may enable understanding of the mechanisms, and estimation of admissible burdens that can be applied to the environment, also may indicate the problems appearing during the use of natural supplies, and simultaneously may indicate the proper direction of development. The remedy for environmental problems was introduced under the name of sustainable development.

The main foundations of the notion of sustainable development were formulated in the report „*Our Common Future*" in 1987 [1]. The sustainable development is the widely applied notion, but interpreted on various ways. In the majority of cases the definitions relate to the equilibria of the environment, the economy and society. This is the strategy of the endeavor to the stately life within the limits, determined by that what is biologically and physically possible with the assurance of natural equilibrium and the durability of processes [2], [3].

Various definitions and various interpretations of sustainable development existing in the literature frequently emphasize its multidimensional character. [4]

During the years 1950 – 1960 it was also recognized that environmental problems may also result from food economy and agriculture [5].

Consequently in the dissemination of sustainable development in the global scale [6] the possibility of the implementation of this conception also in agriculture should be determined. The sustainable development joins the conception of multi-functionality, the creation of conditions for the various forms of the economic activity, respect of environmental, cultural and social values on country areas.

Small elementary efficiencies are one of the essential barriers for the implementation of this strategy in the agrotechnical system. Effective workings towards harmonious, sustainable husbanding of resources must, however, have be supported by the sustainable development of energy [7] , which should be taken into account in the biofuels production.

The need for the adaptation of technology to the requirements of sustainable development determines the directions of scientific investigations in the range of agricultural. It also indicates that renewable energy may happen to be the effective way to achieving the sustainable development [9]. Recently also computer modeling studies suggested [10] a positive role of biofuel production towards sustainability of agriculture.

The productive activity in agriculture may cause pollution of the air. Particularly large agricultural farms might show strong influence with this respect. The efficient forwarding system is one of the factors assuring the development of the modern economy, and as such, it should be taken under the attention, when efficiency in agro-technical system is considered. Because the demand on transportation, both in agricultural as well as in industrial systems, continuously increases, the suitable selection of the transportation means to transported materials and loads seems to play important role.

It is known that agricultural works, consist of numerous agro-technical operations, dependent on the times of the year requiring the appropriate choice of machines and devices as well as the means of transportation. The character of works and continuous improvement of agricultural technologies influence also the choice of the method of tillage.

The aim of the present work is to evaluate the influence of internal transport, i.e. transport of goods and machinery between the fields before, and after agricultural operations performed on the

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fields, on the energetic efficiency of agricultural production subsystem. This evaluation should enable conclusions towards sustainability of agriculture.

2. Methods

The main methodology of the work is the computer modelling based on both: real data from rapeseed production plants, and computations that take into account elementary operations performed in agricultural practice. The later approach enables computation of dependencies based upon derived functions, and assumed ranges of values of variables.

The characteristics of equipment taken into account are listed in the Table 1.

Table 1. Fuel consumption needed for in various tillage styles applied to the one hectare of the winter rape [dm^3/hm^2]

Tillage type	*Tractor*	*Fuel consumption*	
		Without forecrop [dm^3/hm^2]	*With forecrop (lucerne) [dm^3/hm^2]*
Classical	Zetor 5340 (65KM)*	45	50
	Deutz Fahr TI4 Agrotron (140 KM)**	90	100
Surface	Zetor 5340 (65KM)*	37.5	50
	Deutz Fahr TI4 Agrotron (140 KM)**	75	100
Direct sowing	Zetor 5340 (65KM)*	30	50
	Deutz Fahr TI4 Agrotron (140 KM)**	60	100

* specific fuel consumption 5 dm^3/h
** specific fuel consumption 10 dm^3/h
Source: author's computations based on empirical data collected from chosen agricultural farms

3. Results and discussion

3.1. Tillage technology and energetic efficiency of rapeseed production plantation

Energetic efficiency of biofuel production is understood as the ratio of the amount of energy available from the production system to the amount of energy needed to maintain the system working. This definition, however, is often used in the ambiguous way [11], [12]. Doubts are related to the choice of data taken into account in calculations as well as to some aspects of boundary conditions, and to the possibility of including factors previously omitted. The new approach to the computer modelling of energetic efficiency of biofuel production system was recently proposed [13]. The approach contain a possibility of "ab initio" computation from elementary assumptions or

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with the use of empirical data. The energetic efficiency of the plantation can *be* expressed as the ratio P_{ren} /P_{in}, where, P_{ren} , - is the energy obtained ion form of biofuel at the end of production system, and, P_{in}, - is the total energy needed to be supplied in order to enable all the necessary transitions occurring in that system. When, P_{in} , is composed of many contributing fluxes of energy, $P_{in,i}$, it is convenient to define partial energetic effectiveness, ε_i , for individual parts of the system structure.

In such a case [14]:

$$\varepsilon_i = \frac{P_{ren}}{\sum_i P_{in,i}} \tag{1}$$

and the total energetic efficiency of the system can be written as:

$$\varepsilon = \left(\sum_i 1/\varepsilon_i \right)^{-1} \tag{2}$$

In the modelling computations considering the situation when the only one fuel is produced in the system the, P_{ren} , can be expressed as:

$$P_{ren} = S \times M \times \Omega \times V_{ren} \tag{3}$$

where: *S* – is the surface area of plantation, *M* – the mass of crop on the unit of area of plantation, *Ω* – general mass fraction of biofuel in the crop, V_{ren} – low caloric value of the biofuel.

Considering that every machine can work the definite width of the field in the single operation pass, the field has the shape of the parallelogram of the length *D* and the width, *W*, then its surface area is *S* = *DW*, and the slant side has the length:

$$A = \frac{W}{\sin\alpha} \tag{4}$$

In such a case, illustrated in Fig. 1., when the moving machine works on the surface along the length of the field, the during single pass elaborates the fragment of the surface equal to $s_1 = Dw$, the number of necessary strips needed to cover the whole area is q_1, which can be expressed as:

$$q_1 = \frac{W}{w} = \frac{D \times W}{D \times w} = \frac{S}{s_1} \tag{5}$$

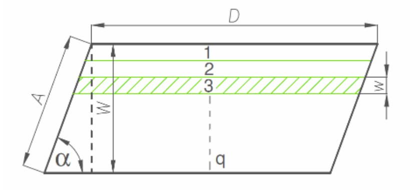

Figure 1. The field elaborated along the length, D

Consequently the length of the route, R, needed to cover the field is equal to:

$$R = q \times A = \frac{D\sin\alpha}{w} \times \frac{W}{\sin\alpha} = \frac{DW}{w} \tag{6}$$

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It can be shown that similar relationship, giving the same result can be derived for motion of machine along the side, A.

The amount of energy consumed in tillage operations is therefore equal to

$$P_{in} = \sum_{i}^{m} \frac{D \times W}{w_i} \times \delta_i \times V_{cal} \quad (7)$$

After the extraction of constants outside of summation one obtains:

$$P_{in} = V_{cal} \times S \times \sum_{i=1}^{m} \frac{\delta_i}{w_i} \quad (8)$$

where P_{in} – is the energy consumed in tillage operations, V_{cal} -the low caloric value of the fuel used for operations (might be fossil fuel or biofuel), S -the surface area of plantation, δ_i - the fuel consumption per unit of the distance passed during the individual agro-technical process, w_i - width of the land strip operated in the single course of i-th operation, m -the number of the agro-technical operations (in each one of the operations the width of the worked field, w_i and the consumption of fuel, δ_i , can be different).

During recent years a number of papers [15 – 17] concerning various technologies of tillage have been published. Concerning rapeseed production several main technologies can be distinguished: classical including plowing and seasoning of soil is used most frequently, but surface method consisting in replacement of plough by the furrow sowing become also popular. The figures (Fig. 2 – Fig. 4) schematically show the operations occurring in several technologies of rapeseed cultivation.

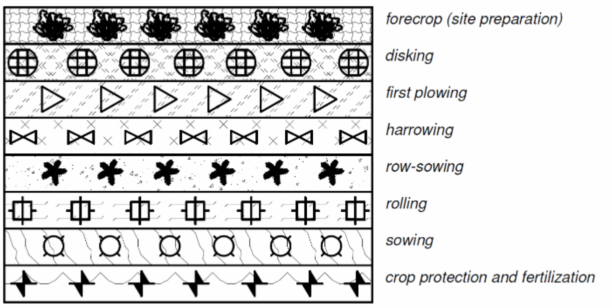

Figure 2. Agro-technical operations during classical cultivation of the winter rape

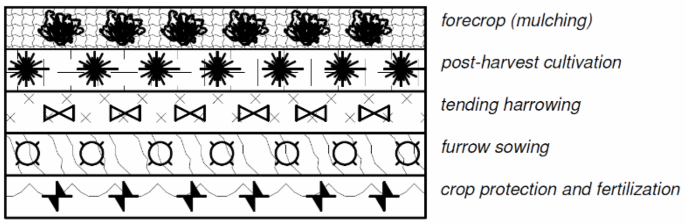

Figure 3. Agro-technical operations during surface cultivation of the winter rape

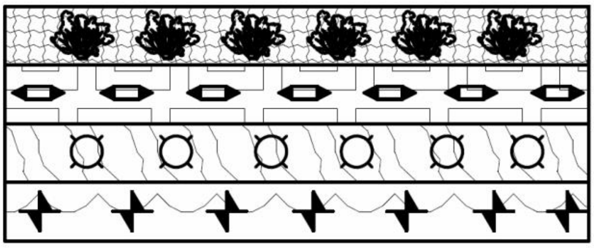

Figure 4. Agro-technical operations during direct sowing cultivation of the winter rape

The rape cultivation is the energy-consuming process, in which the choice of agro-technical operations determines the amount of energy consumed. This amount depends upon time and number of operations (including the eventual forecrop), the specific fuel consumption for a tractor, and the calorific value of the fuel applied. Table 2. gives the values of energy consumption for several choices of a tractor, plantation sizes, types of tillage, and the use of forecrop. The values were computed for calorific value of diesel fuel equal to 36 [MJ/dm^3]. (Variant I - without forecrop, variant II – with forecrop).

Table 2. Energy consumption in variants of the tillage operations on the rape plantations

Area [ha]	*Fuel variant I [l/ha]*	*Fuel variant II [l/ha]*	*P_{in} variant I [MJ]*	*P_{in} variant II [MJ]*	*Area [ha]*	*Fuel variant I [l/ha]*	*Fuel variant II [l/ha]*	*P_{in} variant I [MJ]*	*P_{in} variant II [MJ]*
***Classical** Zetor (65KM)*					***Classical** Deutz Fahr (140 K)*				
3	45	95	4860	10260	3	90	190	9720	20520
12	45	95	19440	41040	12	90	190	38880	82080
30	45	95	48600	102600	30	90	190	97200	205200
***Surface** Zetor (65KM)*					***Surface** Deutz Fahr (140 KM)*				
3	37.5	87.5	4050	9450	3	75	175	8100	18900
12	37.5	87.5	16200	37800	12	75	175	32400	75600
30	37.5	87.5	40500	94500	30	75	175	81000	189000
***Direct sowing** Zetor (65KM)*					***Direct sowing** Deutz Fahr (140 KM)*				
3	30	80	3240	8640	3	60	160	6480	17280
12	30	80	12960	34560	12	60	160	25920	69120
30	30	80	32400	86400	30	60	160	64800	172800

Source: own computations

The amount of energy produced from rapeseed grain is given in Table 3. The calorific value of biodiesel fuel was accepted as V_{cal} = 34.59 [MJ/l]

Table 3. Rapeseed biodiesel yield, and energy production from fields of various sizes

Field area [ha]	**Biodiesel yield [l/ha]**	**Energy yield [MJ]**
3	1520	157730.4
12	1520	630921.6
30	1520	1577304

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Source: own computations

The data from Table 2. and table 3 enable computation of the net energy gain after energy consumption in agricultural operations was subtracted from the total energy yield. The values of net energy gain for various variants of production are, in turn, given in Table 4.

Table 4. Net energy gain from rapeseed plantation

Area [ha]	P_{net} *I [MJ]* *Zetor*	P_{net} *II [MJ]* *Zetor*	P_{net} *I [MJ]* *Deutz*	P_{net} *II [MJ]* *Deutz*
Classical				
3	152870	147470	148010	137210
12	611482	589882	592042	548842
30	1528704	1474704	1480104	1372104
Surface				
3	153680	148280	149630	138830
12	614722	593122	598522	555322
30	1536804	1482804	1496304	1388304
Direct sowing				
3	154490	149090	151250	140450
12	617962	596362	605002	561801
30	1544904	1490904	1512504	1404504

Source: own computations

Basing on data from Table 2. and Table 3. it is also possible to evaluate partial energetic efficiency, after tillage operations are taken into account. The values, obtained according to Eq. 1, are listed in Table 5. It is seen that values of partial energetic efficiency are independent on plantation size, but quite substantially depend upon the machine used, and upon the type of production technology. Obviously the simpler is cultivation technology, the higher energetic effectiveness of the plantation. Also the use of a bigger tractor for relatively small plantations, and introducing the forecrop, evidently reduce partial energetic effectiveness of the plantation. Consequently, the forecrop should be used when other than energetic gains are expected.

Table. 5. Partial energetic efficiency of rapeseed plantations, after energy inputs for tillage operations are considered.

Area **[ha]**	P_{ren}/P_{in} *I [MJ]* *Zetor*	P_{ren}/P_{in} *II [MJ]* *Zetor*	P_{ren}/P_{in} *I [MJ]* *Deutz*	P_{ren}/P_{in} *II [MJ]* *Deutz*
Classical				
3	32.45	15.37	16.23	7.69

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12	32.45	15.37	16.23	7.69
30	32.45	15.37	16.23	7.69
Surface				
3	38.95	16.69	19.47	8.35
12	38.95	16.69	19.47	8.35
30	38.95	16.69	19.47	8.35
Direct sowing				
3	48.68	18.26	24.34	9.13
12	48.68	18.26	24.34	9.13
30	48.68	18.26	24.34	9.13

Source: own computations

3.2. The effect of internal transport

Besides of tillage operations performed directly on the field, several transport operations are inseparably connected to agricultural production. Such operations include transport of machines to, and from fields, transport of fertilizers, and crop protection means, as well as transport of crops within the farm. The transport of grain or oil from the farm to an industrial facility needs to be treated separately. As it was computed in [18] the ratio of distance driven outside to the distance driven in the field, R_{out}/R_{agr} , varies between 0.1 and 0.35 for various, typical situation of a plantation with distributed fields. Those values have been used to estimate the energy consumed for internal transport in the present situation. To obtain limiting values of energy spend on transportation, the values of net energy gain (given in Table 4) were multiplied by the ratio R_{out}/R_{agr} , (what correspond to the assumption that energy consumption on the field and outside the field are identically proportional to the corresponding distance driven). The corresponding values of energy spend for transportation are given in Table 6 and table 7. Obviously the values given in Table 7, that correspond to the higher ratio R_{out}/R_{agr}, are much higher than those presented in Table 6.

Table 6. The energy consumed for transportation for the case $R_{out}/R_{agr} = 0.1$

Classical				
Area [ha]	*P_{car} I [MJ]* Zetor	*P_{car} II [MJ]* Zetor	*P_{car} I [MJ]* Deutz	*P_{car} II [MJ]* Deutz
3	15287	14747	14801	13721
12	61148.2	58988.2	59204.2	54884.2
30	152870.4	147470.4	148010.4	137210.4
Surface				
3	15368	14828	14963	13883
12	61472.2	59312.2	59852.2	55532.2
30	153680.4	148280.4	149630.4	138830.4

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Direct sowing				
3	15449	14909	15125	14045
12	61796.2	59636.2	60500.2	56180.1
30	154490.4	149090.4	151250.4	140450.4

Source: own computations

Table 7. The energy consumed for transportation for the case $R_{out}/R_{agr} = 0.35$

Classical				
Area [ha]	P_{car} *I [MJ]* Zetor	P_{car} *II [MJ]* Zetor	P_{car} *I [MJ]* Deutz	P_{car} *II [MJ]* Deutz
3	53504.5	51614.5	51803.5	48023.5
12	214018.7	206458.7	207214.7	192094.7
30	535046.4	516146.4	518036.4	480236.4
Surface				
3	53788	51898	52370.5	48590.5
12	215152.7	207592.7	209482.7	194362.7
30	537881.4	518981.4	523706.4	485906.4
Direct sowing				
3	54071.5	52181.5	52937.5	49157.5
12	216286.7	208726.7	211750.7	196630.4
30	540716.4	521816.4	529376.4	491576.4

Source: own computations

The values of energy consumed in transportation can be finally used to compute partial energetic efficiency of transportation for two limiting values of internal transport contribution to the energy consumed by the production system. These are reported in Table 8 and Table 9.

Table 8. Partial energetic efficiency of internal transport when $R_{out}/R_{agr} = 0.1$

Classical				
Area [ha]	P_{ren} *I*/P_{car} Zetor	P_{ren} *II*/P_{car} Zetor	P_{ren} *I*/P_{car} Deutz	P_{ren} *II*/P_{car} Deutz
3	10.4	10.7	10.7	11.5
12	10.4	10.7	10.7	11.5
30	10.4	10.7	10.7	11.5
Surface				
3	10.3	10.7	10.6	11.4
12	10.3	10.7	10.6	11.4
30	10.3	10.7	10.6	11.4
Direct sowing				

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3	10.3	10.6	10.5	11.3
12	10.3	10.6	10.5	11.3
30	10.3	10.6	10.5	11.3

Source: own computations

Table 9. Partial energetic efficiency of internal transport when $R_{out}/R_{agr} = 0.35$

Area [ha]	P_{ren} I/P_{car} Zetor	P_{ren} II/P_{car} Zetor	P_{ren} I/P_{car} Deutz	P_{ren} II/P_{car} Deutz
Classical				
3	2,95	3,06	3,05	3,29
12	2,95	3,06	3,05	3,29
30	2,95	3,06	3,05	3,29
Surface				
3	2,94	3,04	3,02	3,25
12	2,94	3,04	3,02	3,25
30	2,94	3,04	3,02	3,25
Direct sowing				
3	2,92	3,03	2,98	3,21
12	2,92	3,03	2,98	3,21
30	2,92	3,03	2,98	3,21

Source: own computations

It is seen from Table 8 and Table 9 that values of partial energetic effectiveness for internal transport are quite low. They are independent on plantation size, and only slightly are affected by the types of tractors and methods of tillage. Consequently, it might be expected that they will rather strongly affect the global efficiency of the production system. It is therefore important to choose transportation means appropriately to the task, and generally minimize the use of transport in the real situations.

4. Conclusions

According to Eq. 2 all combinations of partial energetic efficiencies causes a decrease of the global one. The present paper shows that internal transport outside of the fields may drastically decrease the total efficiency of the system. It can be concluded therefore, that planning the production system, one has to take into account possibly small distances between fields, and possibly efficient machinery for both: tillage operations as well as local transport outside of the fields. It has to be also considered that the agricultural subsystem is only a segment in the total chain of operations that have to be performed, not only to produce rapeseed grain, but also convert it to biofuel, which again requires transport, and inputs of energy into industrial operations. It results

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from the present study, that contribution of transport, in some cases bigger than that of tillage operations, should be reduced.

Such reduction may be achieved by several technological, and organizational procedures, reducing distances between facilities, reducing the amounts of transported goods, by preliminary treatment, etc.

Assuming that one of the important conditions for sustainability of agriculture is the assurance of independence upon fossil fuels, it can also be concluded that excessive consumption of energy in agricultural production system may make impossible to achieve sustainability even in the scale of agriculture itself.

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