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EFFECTS OF TILLAGE TECHNOLOGY ON ENERGETIC EFFICIENCY OF RAPESEED PLANTATION FOR BIOFUEL PRODUCTION

Abstract

Biofuel production, as well as any other production processes, involves a number of conversion steps each of those is connected with unavoidable consumption of energy. Since biofuels are intended to replace fossil fuels it is important that the sum of energy inputs into subsequent technological steps does not exceed the energy output from the system. Basing on theoretical model derived recently by present authors, energy requirements for several agricultural technologies are computed, and used for estimation of energetic efficiency of rapeseed plantations dedicated for biodiesel fuel production. The effects of technological choices on energetic efficiency of plantations are demonstrated basing on numerical compu-tations performed using realistic data.

1. INTRODUCTION

Needs to mitigate carbon dioxide emission to atmosphere, and therefore to decrease danger of global warming, drives contemporary fuel production technology into search for various alternative energy sources that would effectively replace fossil fuels [1]. The other reason for such search is expectation of an exhaust of fossil fuels resources, especially that of petroleum, which

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should be replaced by other resources in order to maintain sustainability of economical development. Problems connected with the use of various types of biomass as the source of energy are widely discussed in literature [2-7]. In several recent sources a large variety of agricultural technologies has been presented [8-12]. Recently published handbook [13] presents several technological data of a number of agricultural machines including the fuel consumption. Differences in available tillage methods lead to very diversified energy consumption in different sets of operation being performed. This leads to the conclusion that energetic efficiency of plantations using different technologies might substantially differ. Since several economical instruments, e.g. "green certificates" or "Renewable Energy Certificates", increase financial profitability of investments into biofuel plantations, the attention paid to the technological sense of particular solution might be decreased, and some important factors might be overlooked. It is therefore important to investigate how various technical effects play role in determination of energetic efficiency of any technical solution being undertaken.

The present authors [14] have recently published a theoretical model of energetic efficiency of agricultural plantation designed for production of biomass for biofuels. The model includes the most important contributions to energy efficiency, and permits calculations for any practical situation, as well as analysis of some dependencies.

The aim of the present work is to estimate effects of the choice of agricultural technology on the energy efficiency of plantation (practically defined in analogous manner as EROEI).

2. THE MODEL

Biofuel production, as well as any other production processes, involves a number of conversion steps, and a number of necessary operations. Each of the steps is connected with unavoidable consumption of energy. The energetic efficiency of plantation, can be defined as a ratio of total energy produced to the sum of energy inputs. On the side of outputs it can be expressed in terms of crop yield, caloric values and mass fractions of crop components used for biofuel production. Fuel consumption and caloric values of the fuel used in subsequent agricultural operations, as well as transportation distances and fuel consumption during transportation of goods (production means and products) between fields used in production and also during transport to customers, and its caloric value, as well as energy embodied in production means – determine energy inputs to the production system. Embodied energies (amounts of energy used for production of a particular good – the idea generalized to the notion of emergy contained in corresponding technical means (like fertilizer or e.g. insecticide or in machines) [15]. Consequently energetic efficiency can be expressed as:

$$\varepsilon = \frac{E_{bio}}{E_{ex}+E_{tr}+E_{emb}} \tag{1}$$

where: E_{bio} – is energy obtained from the field,
E_{ex} – is energy expended on tillage operations,
E_{tr} – is energy consumed for transportation outside of fields,
E_{emb} – is a fraction of embodied energy contained in production means, that is spend during tillage operations and transport.

The contributing energies are further expressed as follows – at first energy obtained from the plantation equals:

$$E_{bio} = A \times M_{crop}\left(c_f, c_w, c_{cp}, \ldots\right) \times \gamma \times \sum_{k=1}^{n} \alpha_k \times W_{bio,k} \tag{2}$$

where: A – plantation area,
M_{crop} $(c_f, c_w, c_{cp}, \ldots)$ – crop yield dependent upon concentrations: c_f – fertilizer, c_w – water, c_{cp} – crop protection means, maintained during cultivation. This dependence should be estimated on the basis of empirical field studies.
γ – general mass fraction of biofuel in the crop,
α_k – mass fraction of k species of biofuel,
$W_{bio,k}$ – low caloric value of k-species of biofuel.

The other term is the energy consumed on the field during agro-technical operations:

$$E_{ex,agr} = W_{fuel} A \times \sum_{i=1}^{m}\left[\frac{\omega_i}{d_i}\right] + \sum_{i=1}^{m}\sum_{k=1}^{K} \gamma_k \times Em_{ik} \tag{3}$$

where: ω_i – the fuel consumption per unit of the distance passed during the individual agro-technical process,
d_i – width of the land strip operated in the single course of i-th operation
W_{fuel} – the low caloric value of the fuel used for operations (might be fossil fuel or biofuel),
m – the number of the agro-technical operations (in each one of the operations the width of the worked field, d_i, and the consumption of fuel, ω_i, can be different).
γ_k – is a fraction of embodied energy contained in one of the, k technical means employed at i-th operation (machines, fertilizers, etc.). It may be estimated e.g. as ratio of the time of particular operation to the total expected life time of particular equipment.
Em_k – is embodied energy contained in k-th technical mean.

The last term concerns transportation of goods (including crops) outside of the field. This term is especially important for big plantations that have to be arranged in several fields separated sometimes by quite long distances. Contribution of transport is also significant when crops have to be transported through long distance to industrial facilities for processing. It is expressed as:

$$E_{tr} = \sum_{p=1}^{P} L_p \times \{\beta_p \times W_{fuel,tr} + Emt_p\} \tag{4}$$

where:

- L_p – distance driven outside of the field in p-th route,
- β_p – fuel consumption during p route,
- $W_{fuel,tr}$ – low caloric value of the fuel used in transport,
- Emt_p – fraction of embodied energy of a given transportation mean corresponding to the unit of distance driven.

Another factor, do not expressed explicitly in above formulas, however possible to be included in numerical computations, may concern dependence of fuel consumption upon caloric value of the fuel. Such dependence should be determined empirically, and will be very much dependent upon the equipment being used. It is therefore difficult to include it in a general form.

The model described above does not contain any specific assumptions concerning type of plants being cultivated, therefore it is general, and applicable to any plantation. Only substituting specific numerical values corresponding to particular plant limits conclusions to efficiency of plantation of this specific plant.

3. RAPESEED PLANTATIONS

As mentioned earlier there exist several technologies of rapeseed cultivation for biofuel. In the present paper three different approaches will be presented. The first one is a traditional tillage system, while the last is a direct seeding being extremely simplified way of cultivation. This simplified cultivation method, after initially lower yield, is expected to give approximately the same yield as traditional method after the technology is implemented in full. Each of the approaches involve several variants exhibiting different requirements with respect to energy input.

The first method includes ploughing, and some other agro-technical operations and eventually forecrops.

In the other strategy ploughing, and agro-technical operations are evidently reduced., while direct seeding do not contain ploughing and other operations are reduced. Fig. 1 and 2 show consumption of diesel oil in some variants of traditional and direct seeding methods.

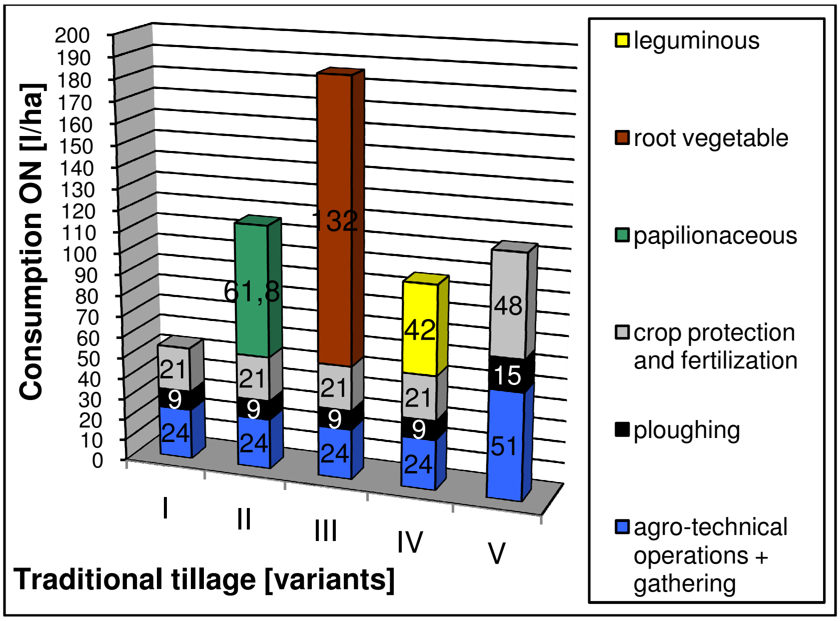

Fig. 1. Consumption of fuel on a hectare of plantation during traditional tillage with various forecrops [source: own study]

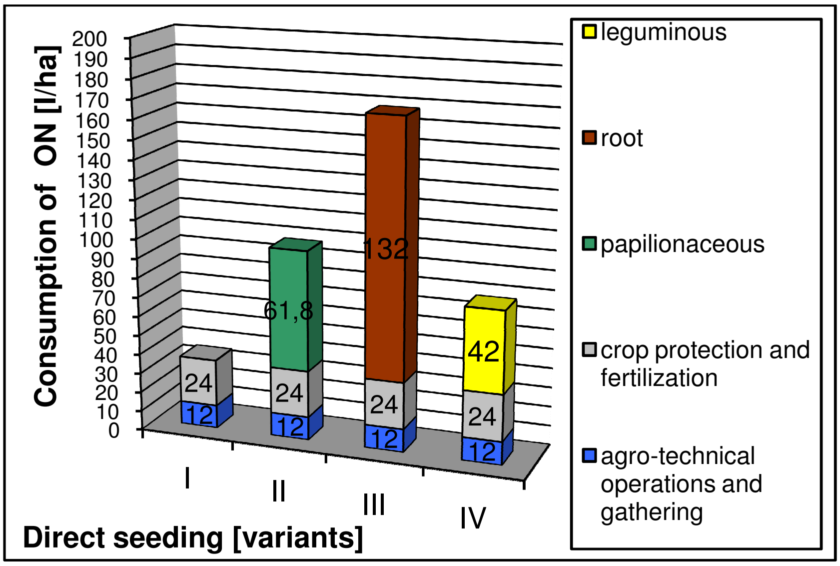

Fig. 2. Consumption of fuel on a hectare of plantation during direct seeding with various forecrops [source: own study]

Tab. 1. Energy consumed during several variants of agro-technical operations for three methods of cultivation for 50 ha plantation

	E_{ex} [MJ]				
	I	II	II	IV	V
traditional	97200	208440	334800	172800	205200
simplified	70200	181440	307800	145800	81000
direct seeding	64800	176040	302400	140400	-

Summarized data presented in Table 1 indicate very large diversity of energy demand of particular variants. At this moment it is difficult to establish embodied energy, not only because of some ambiguities occurring in estimation, but because this contribution should be evaluated for each type of machine and other technical means used in operations. Such data are not available at this stage of work. On the other hand one might consider that agro-technical machines are usually long living, and consequently only small part of embodied energy would require to be taken into account. Taking into account estimations made by Borjesson [16] embodied energy strongly depends upon technical development of producers of agro-technical production means (machinery, fertilizers, herbicides or insecticides), and consequently evidently decreases with time. Basing on the data presented in [16] this contribution may roughly be estimated as total 25000 MJ/year for 50 ha plantation.

The other task is to determine amount of energy obtained from plantation. This task requires some assumptions. Especially in rapeseed planting the plants on the field are not direct energy source. They require further processing in industrial part of the production system. Industrial subsystem contains several steps, and also requires inputs of energy at each conversion step. Since yield of the rapeseed grain from the plantation is known, and the final yield of biodiesel related to the mass of grain is also known, it is assumed here that final amount of energy that is obtained in form of biodiesel after industrial treatment will be used as a reference (E_{bio}). Consequently it is taken that the yield from 1 ha is 3Mg of grain, what gives 380 liters of biodiesel. Therefore for 50 ha taken as an example it gives 150 Mg of grain and 19000 liters of biodiesel. Taking into account caloric value of biodiesel, equal to 34,59 MJ/l one obtains 657210 MJ energy from 50 ha of plantation. Values of the ratio of the above amount of energy obtained from the field to the energy expended during agro-technical operations is presented in Table 2. Those values, being the first approximation of energetic efficiency (or EROEI) vary from two to more than ten depending on chosen variants of tillage. Such result obviously indicate the importance of the choice of production technology.

Tab. 2. Ratio of energy obtained from plantation to energy expended in tillage operations for three methods of cultivation for 50ha plantation

	E_{bio} /E_{ex} I	E_{bio} /E_{ex} II	E_{bio} /E_{ex} III	E_{bio} /E_{ex} IV	E_{bio} /E_{ex} V
traditional	6,8	3,2	2	3,8	3,2
simplified	9,3	3,6	2,1	4,5	8,1
direct seeding	10,1	3,7	2,2	4,7	-

In the computations presented so far transport and embodied energy terms (cf. eq. 1) have not been considered. Accepting rough estimation based upon [16] one may correct the results presented in Table 2. Such corrected values are presented in Table 3. As it was presumed, the values shown in Table 3 are lower than those in Table 2. The decrease is of the order of magnitude about 10% to 25%.

Tab. 3. Ratio of energy obtained from plantation to energy expended in tillage operations including rough estimation of embodied energy consumed by utilization of production means for three methods of cultivation for 50ha plantation

	E_{bio} /$E_{ex,agr}$ I	E_{bio} /$E_{ex,agr}$ II	E_{bio} /$E_{ex,agr}$ III	E_{bio} /$E_{ex,agr}$ IV	E_{bio} /$E_{ex,agr}$ V
traditional	5,4	2,8	1,8	3,3	2,9
simplified	6,9	3,2	2	3,8	6,2
direct seeding	7,3	3,3	2	4	-

Concerning transport energy term, describing energy used for transport outside of the fields, it is easy to compute for the specific cases, when distances outside the fields are explicitly specified. It is difficult, however, if not impossible, to formulate a general rule that would give a relationship between field's areas and distances separating those fields. To overcome this problem, and present some – possibly general solution – it is proposed to assume that energy used for transport should not exceed some fraction of that part of energy obtained which exceeds the total energy input into agro-technical operations. Assuming that this fraction is 10% one obtains the total distance that could be driven outside of the fields:

Tab. 4. The total distance that can be driven outside of the field under assumption that the consumed energy for transport is 10% of the energy gain above the input of energy into agro-technical operations.

	$D_{tr0,1}$ I [km]	$D_{tr0,1}$ II [km]	$D_{tr0,1}$ III [km]	$D_{tr0,1}$ IV [km]	$D_{tr0,1}$ V [km]
traditional	4954	3924	2754	4254	3954
simplified	5204	4174	3004	4504	5104
direct seeding	5254	4224	3054	4554	-

The values shown in Table 4 seem to be quite large, but for better estimation of their real meaning it is necessary to take into account some details of the needs. The yield of rapeseed grains is about 3 Mg from hectare, this means that from the plantation 50 ha, taken as an example, the total amount of grains is 150 Mg. This Amount of grains can be transported by at least 50 trucks of 3 Mg capacity (the volume of 3 Mg of grains might exceed the volume capacity of a truck). Consequently, the distance given in table 3 is the total distance available for all those truck or for several courses made by smaller number of trucks. Sum of distances that can separate fields and industrial facilities for each of tillage variants (which assure that total distance driven by required number of trucks, in eventually a number of courses would be equal to those given in Table 4) is presented in Table 5.

Tab. 5. The total distance that can separate the fields and industrial facility under assumption that the consumed energy for transport is 10% of the energy gain above the input of energy into agro-technical operations

	$D_{tr0,1}$ I [km]	$D_{tr0,1}$ II [km]	$D_{tr0,1}$ III [km]	$D_{tr0,1}$ IV [km]	$D_{tr0,1}$ V [km]
traditional	99,08	78,48	55,08	85,08	79,08
simplified	104,08	83,48	60,08	90,08	102,08
direct seeding	105,08	84,48	61,08	91,08	-

It is seen that the plantation, in order to fulfill assumption assuring rational possibility to sell energy obtained above the internal consumption, has to confine activities to distances between 50 and 100 km.

4. CONCLUSIONS

Basing on the model elaborated, and computations performed on the data corresponding to real conditions occurring in agricultural production systems, it can be concluded that in the case of biofuel production, the agro-technical subsystem may assure efficiency (defined as a ratio of the sums of outputs to the sum of inputs of energy) between 1,8 and 7,3. The observed diversity of efficiency results of the choice of agricultural technology (methods of tillage and that of cultivation, fertilizing, crop protecting etc.). From technical viewpoint, and requirements of sustainability of the production processes it is important to assure possibly high energetic efficiency in spite of the fact that due to several economic methods of supports offered to producers financial profits might appear independent upon this efficiency. Obviously governmental institutions should also care about compatibility between economic and energetic efficiency.

Another conclusion concerns the size of production systems including agricultural and industrial subsystems. The size of plantations is determined by demand from industrial facility. In the case of very big facility, and correspondingly big demand for rapeseed grain, the distance for grain transportation, as well as for transportation of production means between fields might easily exceed rational distance, and drastically diminish the amount of fuel available for consumption outside of production system.

Further development of the model, by constructing computer program that could be used for analysis of particular case studies, especially prior to investment, will be valuable tool for practical applications, valid for various types of biomass plantations for energetic use.

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