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The role of engineering in organic farming – case energy crops

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Abstract:

Energy self-reliance and a closed nutrient cycle are basic principles of organic farming ever since. Engineering sciences methods in energy accounting may support efforts to introduce these principles into praxis. A method to calculate efficiency of energy crop production including sun energy, direct and indirect energy for cultivation, processing, and conversion into fuel is demonstrated using rape and derived fuels as an example. Every production and conversion step is a process and calculated separately. The overall efficiency includes energy input and output of all processes. The process efficiency of rape cultivation reaches in Finland up to 1100%. However, the overall energy efficiency of rape methyl ester (RME) is 1 to 2 ‰ only. The production of biogas from manure of dairy fed by rape meal results in a process energy efficiency of 33 to 41%, but the overall energy efficiency of RME and biogas together is only 1.2 to 2.5 ‰. In contrast, thermal or photovoltaic solar collectors improve overall efficiency 1 to 3 orders of magnitude compared to fuel production from rape, because the process efficiency of photosynthesis attains about 0.6% whereas solar collector's efficiency reaches about 90%. However, for the time being solar energy based techniques are more expensive than the use of fossil energy sources since environmental benefits in terms of GHG mitigation, reduction of nutrient run off and use of renewable energy do not create cash income in both organic and main stream production. This and the low photosynthesis efficiency in Finland encourage bio-refinery enterprises to purchase energy crop produce for fuel production from the tropics. Mineral fertilisers as well as genetic modification increase the technical efficiency of photosynthesis. Thus, environmental pollution of mainstream agriculture is exported to developing countries in the tropics.

Introduction and Objectives:

Engineering sciences lead a shadowy existence within organic farming research. However, agricultural machinery and buildings cause up to 40% of production cost in organic farming too. The high cost of technical input forces to specialisation of farm production, narrow crop rotations, and dependency from fossil fuels and run contrary to organic farming principles. In short, the entropy of organic farming systems increases. However, a physical and technological approach and engineering proficiency may contribute to the aims of organic farming also in respect of energy crop issues. The crop scientist focuses his research on high quantity and quality of yield based on a sustainable tilth. The engineer is interested in maximisation of the process efficiency. He interprets the crop scientist's approach as maximisation of photosynthesis efficiency. Objective of this paper is to support the assessment of energy crop production in organic farming applying engineering sciences methods in energy accounting.

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Methods:

The engineer quantifies the sustainability of energy crop production by means of the overall efficiency η_O that is the energy output divided by the energy input of all processes involved:

$$\eta_O = \left(\sum_{i=1}^{n} (A_i \cdot S_i \cdot \eta_i) \right) \cdot \left(\sum_{i=1}^{n} \left[A_i \cdot (S_i + P_i + K_i) \right] \right)^{-1}$$

A denotes the area, S the solar energy, P the energy input of crop cultivation, K the energy input of fuel conversion, η_i the technical efficiency of photosynthesis and i the member of crop rotation. The crop scientist concerns for η_i and to some extent for P while K and P is of engineers and partially animal production scientist's interest. Please note that the solar-radiation intensity is limited like the cultivating area too. The equation is applicable for farm level, national level, and worldwide. However, it does not take into consideration the energy saving potential of crop fibre for heat insulation. The calculation of the process energy efficiency includes the process energy input and the free energy (exergy) before and after processing. The engineer considers photosynthesis, cultivation, and conversion each as process. The process efficiency of burning biomass for heat production depends only on incinerator efficiency and on energy input for transport of biomass and ash. Additional treatment like pelleting, extraction of oil, anaerobic digestion, ethanol fermentation etc. raises the energy input considerably. The production of ethanol from corn renders always a negative energy balance due to the thermodynamic laws (PATZEK 2004). Crop processing generates usually different products. Some are suitable for energy production others for fibre production, human nutrition or animal feed. This fact causes a methodical problem, called allocation. The process energy for rape crop production may be allocated to seed, straw and roots. The process energy input for extraction, refining, and esterification of rapeseed oil has to be split between rape methyl ester (RME), meal, and glycerine, the by-product of esterification of rape oil. Depending on the allocation method, the process energy balance may diverge in a wide range.

Results and Discussion:

Tab. 1 shows a chain of processes of rape production and processing, their efficiencies and the resulting cumulated overall efficiency. The results show that the high process energy efficiency of the rapeseed cultivation fosters common acceptance of rape as energy crop. Even under Finnish climate conditions, exergy of rape crop exceeds up to 11-times the energy input for production and exergy of seed up to 3.7-times. Conversion of rapeseed into fuel decreases the energy surplus. Rape methyl ester (RME) delivers still 1.2-fold the energy input for cultivation and conversion. The whole rape crop (root, straw, seed) contains 3 to 6 ‰ of the overall energy input, RME 1 to 2 ‰ only. Animal production converts rape meal feed into manure, which is suitable for anaerobic digestion together with glycerine. The biogas augments the overall efficiency additionally 0.2 to 0.5 ‰. Rape cultivation requires a 4 to 7-year crop rotation. This and the low overall efficiency make it difficult for an organic farm in Finland to achieve energy self-sufficiency replacing diesel fuel by RME.

The technical efficiency of the photosynthesis limits the maximum energy yield and reaches up to 5% of the sun energy input in the tropics and up to 0.8% in Finland (LAMPINEN et al. 2006). For rape, the efficiency is 3.3 to 6.3 ‰ only. Mainstream production renders better photosynthesis efficiencies on expense of lower cultivation efficiencies. Because of photosynthesis' low efficiency, even a double biomass yield improves the overall efficiency only marginally. Vice versa, 20 to 56% lower energy input in organic crop production (MÄDER et al. 2002) increases only marginally the overall efficiency.

By comparison, the efficiency of a photovoltaic collector is 165 to 248-fold better than power production by burning biomass or biogas produced from rapeseed and rape straw. The efficiency of the thermal collector exceeds heat production from burning the rape crop 157 to 443-fold. However, storage and continuous production of power and heat from sun energy is very limited. For that reason, the storage of sun energy in liquid carbon hydrates is subject of present research. Future biotechnology produces hydrogen and liquid carbon hydrates from CO_2 and H_2O powered by sun energy (CENTI et al. 2006).

Tab. 1: Energy input, energy output, process efficiency and overall efficiency of rape production and rape processing in Finland.

Process	***Input*** **kWh m^{-2} a^{-1}**		***Output*** **kWh m^{-2} a^{-1}**		***Process-efficiency %***	***Overall efficiency %***
crop cultivation	direct and indirect energy[a]	0.3 - 0.8	root straw seed[b]	3.3 - 6.3	*262 - 366* *262 - 366* *262 - 366*	*787 - 1100*
photo-synthesis	sun light	1000	root straw seed[b]	1.1 - 2.1 1.1 - 2.1 1.1 - 2.1	0.11 - 0.21 0.11 - 0.21 0.11 - 0.21	0.33 - 0.63
incineration	straw seed	2.2 - 4.2	*calorific heat*	1.76 - 3.78	80 - 90	0.18 - 0.38
oil and meal production	seed energy	1.1 - 2.1 0.1	oil. meal total	0.64 - 1.21 0.46 - 0.89 1.1 - 2.1	52.9 - 55.1[c] 38.7 - 40.3[d] 91.7 - 95.5[e]	0.06 - 0.12[c] 0.05 - 0.09[d] 0.11 - 0.21[e]
bio-refinery	seed energy[f]	1.1 - 2.1 0.1 - 0.2	RME meal	0.64 - 1.21 0.46 - 0.89	84.6 - 95.5[e]	0.11 - 0.21[e]
milk production	meal direct and indirect energy	0.46 - 0.89 0.2[g]	milk[h] manure heat, CH_4 total	0.09 - 0.18 0.16 - 0.31 0.21 - 0.40	14.1 - 16.5 17.1 - 19.1 22.6 - 25.2 53.9 - 60.7	0.01 - 0.02 0.02 - 0.03 0.02 - 0.04 0.05 - 0.09
anaerobic digestion	manure heat and power	0.16 - 0.31 0.03 - 0.15	biogas[i] effluent[i]	0.08 - 0.15 0.08 - 0.15	33.3 - 41.7 33.3 - 41.7	0.01 - 0.02 0.01 - 0.02
power production	biogas	0.08 - 0.15	power heat	0.03 - 0.05 0.05 - 0.10	33.3 66.7	<0.01 <0.01
thermal collector	sun energy manufacture	1000 2.3[j]	heat	600 - 800	60 - 80	59.9 - 79.8
photovoltaic collector	sun energy manufacture	1000 6 - 11[k]	power	100 - 150	10 - 15	9.9 - 14.9

[a] Direct and indirect energy input of Finnish agriculture is 0.83 kWh m^{-2} a^{-1}, of which 0.34 kWh m^{-2} a^{-1} fossil fuels, of which 0.07 to 0.14 kWh m^{-2} a^{-1} diesel/RME (LAMPINEN et al. 2006, NYHOLM et al. 2005, ELSAYED et al. 2003, BUGGE 2000, SCHÄFER et al. 1986). [b] Seed yield 160 to 310 g m^{-2}; allocation of energy output: 1/3 seed, straw, and root respectively. [c] In respect of oil. [d] In respect of meal. [e] In respect of oil/RME and meal. [f] Oil extraction 416 Wh kg^{-1} seed; esterification 476 Wh kg^{-1} seed (CAMPA®- BIODIESEL GMBH & CO. KG 2006, http://www.campa-biodiesel.de/cadeunof/cadnumw3.htm). [g] Estimated. [h] Allocation: milk 20.2%; manure 34.4%; heat 40.4%; methane 5% (HORN et al. 1994). [i] Allocation: 50% each. [j] Mass 15 kg m^{-2}; estimated energy input for production 3.9 kWh kg^{-1}; depreciation 25 years. [k] KNAPP et al. 2000.

Farmers own 6.6 million ha land or 19% of Finland's area. A mean photosynthesis efficiency of 5 ‰ results in 472 GWh a^{-1} bio-energy potential (LAMPINEN et al. 2006). Present thermal solar technique operating at 50% overall efficiency occupies only 0.6% of this area to cover the present fossil energy consumption in Finland of 292 GWh a^{-1}.

Conclusion:

Energy crop production is captivating with many win-win situations: environmentally neutral bio-fuels replace polluting fossil fuels, farmers get better prices for energy crops, the agrochemical industry gains from intensification of energy crop production, and turn over of power industry grows due to increasing energy consumption to produce agrochemicals and to process biomass into fuel. As a following, the state tax income improves too. However, better prices for mainstream energy crops may trigger export of environmental pollution at the expense of food production because higher overall efficiency in tropical countries favours the import of organic raw material for bio fuel production. Yet, high process efficiencies of technical processes to convert biomass into fuel justify the production of renewable energy from organic waste and residues. Thus, both organic and mainstream agriculture should not focus on energy crop production but produce high quality food environment-friendly. The overall efficiency of energy production from energy crops will never be competitive with solar techniques. Solar collectors replace fossil fuels for heat production outside agriculture already now sustainable and more efficient. Research on solar-technical processes to produce liquid carbon hydrates from methane, carbon dioxide and water powered by solar energy without diversion into photosynthesis offers much a greater potential than research on energy crop production.

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