Energy balances of different crop rotations with rape

Gisa-Wilhelmine Rathke[1]*, Wulf Diepenbrock[1]
[1]Institute of Agronomy and Crop Science, Martin-Luther-University Halle-Wittenberg
Ludwig-Wucherer-Str. 2, 06108 Halle (Saale), Germany, * Email: rathke@landw.uni-halle.de

ABSTRACT

Data of a field experiment (1994-2001) conducted on a fertile sandy loess in the Hercynian dry region of central Germany were used to determine the productivity and energy efficiency of (i) winter oilseed rape as affected by the preceding crop and (ii) of different crop rotations with rape. The crop rotations included (i) winter barley – winter oilseed rape – winter wheat, and (ii) pea – winter oilseed rape – winter wheat. The energy balance sheets are based on the process analysis (economic method). Within the computations, only the main harvest products (grain, seed) are considered. To describe the energetic efficiency, the parameters energy gain (net energy output), energy intensity and output/input ratio are used.

On the average of the tested years, the energy input increased in the order pea (6.42 GJ/ha*a) < winter barley (10.8 GJ/ha*a), winter wheat (11.5 / 12.7 GJ/ha*a) and winter oilseed rape (16.2 / 15.7 GJ/ha*a). In consequence, the total energy input was slightly higher in the crop rotation winter barley – winter oilseed rape – winter wheat (CR 1; 12.8 GJ/ha*a) than in that one with pea (CR 2; 11.6 GJ/ha*a). Due to the obviously higher yields of winter barley compared to pea, the average energy output of crop rotation CR 1 was clearly higher than in crop rotation CR 2 (145 vs. 125 GJ/ha*a). The significantly yield differences between winter barley and pea did not become balanced by the higher yields of rape grown after peas. Based on these connections, crop rotation CR 1 realized a higher energy gain (132 vs. 114 GJ/ha*a) and a better output/input ratio (11.3 vs. 10.8) than crop rotation CR 2. At the same time, the energy intensity was lower in crop rotation CR 1 compared to CR 2 (134 vs. 147 MJ/GE*a).

Key words: Energy balance sheets, energy efficiency, preceding crop, nitrogen fertilization

INTRODUCTION

In the course of the persistent discussion on environmental effects of farming and restricted availability of fossil energy, it is necessary to receive reliable information on the impact of agricultural activities on the environment and the regional energy budgets. The analysis and drawing up of substance and energy fluxes is an appropriate measure for the assessment of energy binding of cultivated crops in dependence on the production intensity. Due to the subsequent delivery of nitrogen (N) and, thus, the reduction of nitrogen fertilizer, the integration of legumes in crop rotations is classified as energetically favourable. In this case it remains unconsidered that the biological N2-fixation of legumes is an energy-expensive process. Accordingly, the question about the influence of legumes compared to cereal preceding crops on the energy balance of winter oilseed rape and the total crop rotation has to be observed.

MATERIALS AND METHODS

For the energetic evaluation of two different crop rotations with winter oilseed rape, data of the years 1994 to 2001 were obtained from a field experiment conducted in the Hercynian dry region in central Germany. The average annual precipitation was 551 mm, and the long-term mean air temperature 9.2 °C (1966-1996). The soil is a sandy loam classified as Stagno-luvic Gleysol. It is susceptible to surface sealing and crust formation; water logging and drought stress may adversely affect the growth of the crops. Water is the most limiting factor for crop yield in many years.

The tested crop rotations were (i) winter barley – winter oilseed rape – winter wheat and (ii) pea – winter oilseed rape – winter wheat. To winter barley and winter wheat uniform nitrogen (N) rates of 110 kg N/ha*a were given as CAN (27% N). The nitrogen rate applied to winter oilseed rape corresponded to 140 kg N/ha*a after preceding crop pea and 150 kg N/ha*a after preceding crop winter barley, respectively. It was also applied as CAN. No fertilizer was given to pea. In all cases, the use of pesticides took place in dependence on the infestation. The different cultures were harvested annually. For each crop rotation six rotations were evaluated and averaged.

Concerning the process analysis (economic method) described by Hülsbergen et al. (2001), in this study only fossil energy resources are included in the energy balance sheets while the energy input via human labour and solar energy is excluded. For the production of 1 kg N an energy input of 35.3 MJ/kg N was assumed. The energy input for drying, storage, and transport from the farm to the consumers were not taken into account. The energy output was calculated by multiplying the dry matter yield by the calorific value of the plant material. Based on energy input and energy output, different energetic parameters were calculated (cf. Hülsbergen et al. 2001).

The data were subjected to a statistical analysis using the PROC GLM (Generalised Linear Models) procedure of the SAS system. The treatments were compared using the least significant difference (LSD) test at the 0.05 level of probability. The LSD test was used to compare the treatment means when the Newman-Keuls test was significant.

RESULTS

In the middle of all years, the energy input ranged from 6.42 GJ/ha*a for pea to maximum 16.2 GJ/ha*a for winter oilseed rape. Winter barley (10.8 GJ/ha*a) and winter wheat (11.5-12.7 GJ/ha*a) had a medium position. It turned out that the crop-specific energy input differed considerably in dependence on means of production (fertilizer, diesel, machines; Table 1). Because of the greater inputs for N fertilizer and pesticides as well as the higher requirement for diesel and machines, the energy input was clearly higher for winter oilseed rape than for the other crops. In all cases, the relative share of seed material and plant protection was relatively low. The energy input of the whole crop rotation was only slightly affected by the different preceding crops to winter rape. In the crop rotation winter barley – winter rape – winter wheat (CR 1) the average energy input was as high as 12.8 GJ/ha*a compared to 11.6 GJ/ha*a in the crop rotation pea – winter rape – winter wheat (CR 2).

Table 1: Crop specific breakdown of energy input (GJ/ha*a)

Item	Winter barley	Pea	Winter rape		Winter wheat	
			CR 1	CR 2	CR 1	CR 2
Diesel	3.02	2.06	4.59	4.60	3.26	3.94
Seed material	0.81	1.26	0.16	0.16	1.10	1.10
N	3.91	0.00	5.33	4.97	3.91	3.91
P_2O_5	0.26	0.26	0.26	0.26	0.26	0.26
K_2O	0.33	0.33	0.33	0.33	0.33	0.33
Plant protection	0.72	1.08	1.39	1.39	0.85	0.85
Machines	1.74	1.43	4.09	4.01	1.79	2.28
Total	10.8	6.42	16.2	15.7	11.5	12.7

CR 1: crop rotation winter barley – winter rape – winter wheat; CR 2: crop rotation pea – winter rape – winter wheat

As can be seen from the figures given in Tables 2 and 3, the crops also differed significantly in dry matter production, energy output, and energy use. The highest dry matter yield and energy output were realized by winter wheat (8.16-9.90 t/ha, 152-184 GJ/ha*a). Winter barley (8.19 t/ha, 152 GJ/ha*a) and winter oilseed rape (4.58-4.72 t/ha, 131-135 GJ/ha*a) had a medium position, while pea (3.05 t/ha, 56.7 GJ/ha*a) ranked most unfavorably. In consequence, a yield of 6.98 t/ha and an energy output of 145 GJ/ha*a were achieved in crop rotation CR 1 compared to 5.89 t/ha and 125 GJ/ha*a in CR 2. Moreover, crop rotation CR 1 realized an obviously higher energy gain (132 GJ/ha*a vs. 114 GJ/ha*a) and a better output/input ratio (11.3 vs. 10.8) than crop rotation CR 2. At the same time, the energy intensity was lower in CR 1 than in CR 2 (134 MJ/GE*a vs. 147 MJ/GE*a).

Table 2: Energy input, yield, energy output and energetic parameters in crop rotation 1

Parameter	Unit	Winter barley	Winter rape	Winter wheat	CR 1
Energy input	GJ/ha * a	10.8	16.2	11.5	12.8
Yield, dry matter	t/ha	8.19	4.58	8.16	6.98
Energy output	GJ/ha * a	152	131	152	145
Energy gain	GJ/ha * a	141	115	140	132
Energy intensity	MJ/GE * a	110	185	108	134
Output/input ratio		14.1	8.09	13.2	11.3

GE: grain equivalent (barley and wheat grains: 10.0 GE/t FM; rape seeds: 17.0 GE/t FM)

Table 3: Energy input, yield, energy output and energetic parameters in crop rotation 2

Parameter	Unit	Pea	Winter rape	Winter wheat	CR 2
Energy input	GJ/ha * a	6.42	15.7	12.7	11.6
Yield, dry matter	t/ha	3.05	4.72	9.90	5.89
Energy output	GJ/ha * a	56.7	135	184	125
Energy gain	GJ/ha * a	50.2	119	171	114
Energy intensity	MJ/GE * a	173	170	98.2	147
Output/input ratio		8.82	8.59	14.5	10.8

GE: grain equivalent (pea and wheat grains: 10.0 GE/t FM; rape seeds: 17.0 GE/t FM)

DISCUSSION

Generally, the position within a crop rotation and the crop specific fertilization affect yield and quality of agricultural crops as well as its energetically efficiency. In this context, a positive influence of legumes on the following crop is frequently described (cf. Strasil 1990, Guy and Gareau 1998). In dependence on the production management, there is a need for an economic and ecological assessment of the corresponding cultivation systems. In both cases, the energy balance is a suitable instrument. Therefore it was used in this study.

The determined crop-specific energy input for cereals, pea and winter rape lie within the range described in literature (Biermann et al. 1999, Küsters and Lammel 1999, Hülsbergen et al. 2001, Moerschner and Lücke 2002). In all studies, the mineral nitrogen fertilization is a decisive factor. According to Hülsbergen et al. (2001), its relative share goes up to 44.6%, depending on the crop and the fertilizer regime. Hence, to diminish the energy input in crop production requires reduced mineral nitrogen fertilization. Under these conditions the nitrogen supply can take place via the integration of legumes into the crop rotation. It is assumed that the plant available nitrogen in the soil can be increased by the mineralization of the legume residues and, in consequence, the required energy input for fertilization can be reduced. However, the nitrogen supply and energy input to winter rape were only slightly reduced by the preceding crop pea (10 kg N/ha corresponding to 0.36 GJ/ha*a) compared to preceding crop barley. The energy input for the whole crop rotation was mainly reduced by the low energy input to pea. Due to the high soil fertility, high dry matter yields and energy outputs were obtained for cereals and winter rape. Despite, the yield realized for pea was on a lower level. For each culture, the energy output was much higher than the energy input. The crop-specific order for the energetic parameters energy gain, energy intensity and output/input ratio corresponds predominantly to the data given in literature (Biermann et al. 1999, Küsters and Lammel 1999, Hülsbergen et al. 2001, Moerschner and Lücke 2002). Nevertheless, in contrast to the observations of Strasil (1990) the crop rotation with pea did not produce more energy than the crop rotation without legumes. This results from the low yields of pea and, in consequence, only small amount of plant available nitrogen for the reduction of nitrogen fertilizer to the following crop. Furthermore, the low yields of pea did not become balanced by the higher yields of winter oilseed rape after pea compared to the preceding crop winter barley. To exert a positive influence on the energy balance of winter rape and the whole crop rotation, clearly higher residues of pea as a source for nitrogen are necessary. Otherwise the crop rotation winter barley – winter rape – winter wheat has to be preferred from energetic view.

REFERENCES

Biermann, S., G.-W. Rathke, K.-J. Hülsbergen, W. Diepenbrock, 1999: Energy Recovery by Crops in Dependence on the Input of Mineral Fertilizer. Research report on behalf of the European Fertilizer Manufacturers Association (efma).

Guy, S. and R. Gareau, 1998: Crop rotation, residue durability, and nitrogen fertilizer effects on winter wheat production. Journal of Production Agriculture 11, 457-461.

Hülsbergen, K.-J., B. Feil, S. Biermann, G.-W. Rathke, W.-D. Kalk and W. Diepenbrock, 2001: A method of energy balancing in crop production and its application in a long-term fertilizer trial. Agriculture, Ecosystems and Environment 86, 303-321.

Küsters, J. and J. Lammel, 1999: Investigations of the energy efficiency of the production of winter wheat and sugar beet in Europe. European Journal of Agronomy 11, 35-43.

Moerschner, J. and W. Lücke, 2002: Energy investigations of different intensive rape seed rotations - a German case study. In: Ierland, E.C. van and A.O. Lansink (eds.): Economics of Sustainable Energy in Agriculture. Kluwer Academic Publishers, Dordrecht, 14 p.

Strasil, Z., 1990: Energetická bilance osevních postupü s rüznou strukturou plodin. Rostlinná Výroba 36, 1-7 (engl. summary).