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ENERGY INVESTIGATIONS OF DIFFERENT INTENSIVE RAPE SEED ROTATIONS – A GERMAN CASE STUDY

Johannes Moerschner[1], Wolfgang Lücke[2]
[1]Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Heßbrühlstr. 49a, D-70550 Stuttgart; e-mail: jm@ier.uni-stuttgart.de
[2]Institute for Agricultural Engineering, University of Göttingen, Gutenbergstr. 33, D-37075 Göttingen, Germany

ABSTRACT

Energy use, energy intensity and energy productivity can be applied as a kind of standard for energy related comparisons of products, production processes, farms or farming systems. In this contribution the impacts of different intensive rape seed rotations on these criteria are compared based on data out of nine years of investigation at two sites nearby Göttingen in Lower Saxony, Germany. The advantages of the investigated systems depend on the used energy criteria and on the functional units chosen. Potential options for changes in cropping strategies with regard to energy reduction were identified to be strongly dependend on the specific local conditions.

INTRODUCTION

Investigations on energy aspects can be applied to illustrate differences in environmental characteristics of agricultural production systems. Energy use is generally correlated with greenhouse gas emissions and with depletion of natural resources. In order to reduce both, emissions as well as depletion of natural resources, potentials for energy saving in farming activities have to be identified. This may lead to site specific optimised energy intensities in production. Furthermore, potentials for a substitution of fossil fuels used on farm by renewable ones may be derived in a second step from an energy analysis as presented here, e.g. application of biofuels instead of diesel fuel.

MATERIALS AND METHODS

The energetical investigations are based on cropping data of the years 1989-1998 from the large scale INTEX-project at the University of Göttingen. In two project periods (1989-94 and 1994-98 resp.), four and three different cropping systems respectively were grown simultaneously on two different locations nearby Göttingen. *Reinshof* with its more favourable arable conditions and its high yield potential can be considered as a premium location. In contrast to this, *Marienstein* is a strongly varying location with heavy soils. Situated on the slope of the river Leine, this site is rather typical for the hilly regions of Lower Saxony. Each plot had a size of 1,3 ha to 4,1 ha. Details on further findings of other researchers dealing with economical and ecological aspects of the INTEX-project are found in GEROWITT and WILDENHAYN (1997) and STEINMANN and GEROWITT (2000).

The presented results below are focussed on the conventional reference systems called 'Good farming practice' with oil seed rape, winter wheat and winter sown barley as typical regional rotation compared to three different integrated farming systems (*Table 1*).

Table 1: The investigated cropping systems of INTEX

Farming system	Abbreviation	Years investigated
‚Good farming practice‘	Conv I+II	1989-1998
‚Integrated'	Int	1989-1994
‚Integrated flexible‘	Int-a	1994-1998
‚Integrated without plough‘	Int-b	1994-1998

The integrated rotations were adapted according to their intensity of soil cultivation, fertilisation and pesticide use. Furthermore they were extended by one additional crop (field beans, grown after winter wheat until 1994; since 1994 one year of annual set aside at the end of the crop rotation instead) and since 1994 winter sown barley was replaced by oats. Due to the changes, since 1994 oil seed rape in the integrated farming systems was followed by oats, winter wheat and finally by an annual set aside as last year in the rotations.

In the calculations primary energy input (PE) for diesel fuel, motor oil, electricity, seeds, mechanisation, chemical fertilisers (N, P, K, Ca, S) and pesticides (considered as kg active substances applied per ha) was taken into account. The so-called ‚cumulated energy requirements‘ include the energy use during the whole life cycle. Energy demand for production, use and disposal of each product is assumed to consist of the supply of the end energy used during the life cycle and all transportation processes involved.

Diesel fuel and motor oil use on farm were not measured, but calculated with a model, based on BORKEN ET AL. (1999). The applied amount of P and K fertiliser was calculated with mean figures for the nutrient export by kernel yield [kg t yield^{-1}], the use of CaO was assumed to be 300 kg (ha a)$^{-1}$ according to information of the regional extension service. Drying of yield with heated air was excluded by system definition. As a simplification for modelling the supply of end energy is considered to be the same for all means of production, e.g. electricity is assumed to be provided always in the same way, regardless whether it was actually used for farm activities or for other purposes in the preceding process chains. The energy coefficients used for the energy input calculation are listed in *Table 2*.

Table 2: Energy coefficients used for energy accounting (own calculations, based on Gaillard et al. 1997, Kaltschmitt and Reinhardt 1997, Patyk and Reinhardt 1997)

Supplies		**Primary Energy coefficients**
Direct Energy	- Diesel fuel, Motor oil (2 % of fuel)	47,82 MJ/kg
	- Electricity	11,39 MJ/kWh
Seeds (energy for providing the seeds only)	- Field beans	3,55 MJ/kg
	- Grass, Clover and other fine seeds	12,21 MJ/kg
	- Oats	3,28 MJ/kg
	- Oil seed rape	8,43 MJ/kg
	- Sunflowers	3,55 MJ/kg
	- Winter sown barley	3,45 MJ/kg
	- Winter wheat	3,02 MJ/kg
Mineral fertilisers[a]		
Nitrogen	- Urea	59,07 MJ/kg N
	- Urea ammonium nitrate (UAN, liqu.)	52,33 MJ/kg N
	- Calcium ammonium nitrate (CAN)	47,18 MJ/kg N
	- Ammonium sulphate (AS)	17,41 MJ/kg N
Phosphate	- Triple-Superphosphate (TSP)	43,83 MJ/kg P
Potash	- MOP, 40 % K_2O	12,99 MJ/kg K
Limestone	- Calcium carbonate	2,41 MJ/kg Ca
Sulfur	- Ammonium sulphate (AS)	17,41 MJ/kg S
Pesticides	- Active substance	274,46 MJ/kg AS
Farm machinery	- Tractors	122,45 MJ/kg
	- Self propelled harvesters	112,88 MJ/kg
	- Cultivation machinery	109,75 MJ/kg
	- Other machinery and trailers	101,25 MJ/kg

[a] Conversion factors element/nutrient: $P/P_2O_5 = 0,428$; $K/K_2O = 0,826$; $Ca/CaO = 0,714$

Net energy yield was calculated with the figures in Table 3. The gross energy content (GE) of all seeds was subtracted from total energy yield before further calculation, because it has to be considered as a regenerative energy input from a previous time period. The energy coefficients for seeds as shown in *Table 2* reflect only the energy necessary for their supply; energy content is given by the figures in *Table 3*.

Table 3: Gross energy content of arable products (own calculations based on UNIVERSITÄT HOHENHEIM 1997); reference: 1 kg at standard moisture content[a]

Arable products		**Gross Energy** (GE)
Seeds and kernel yield identical	- Field beans	16,42 MJ/kg
	- Oats	16,30 MJ/kg
	- Oil seed rape	25,72 MJ/kg
	- Winter sown barley	15,79 MJ/kg
	- Winter wheat	15,79 MJ/kg
Other seeds	- Grass, clover and other fine seeds	16,40 MJ/kg
	- Sunflowers	25,12 MJ/kg

[a] Oil seed rape: 91 % dry matter content (DM); fine seeds: 100 % DM; Others: 85 % DM

RESULTS

System comparisons of energy input as well as of energy intensity and energy productivity for the farming systems were carried out on different levels. Due to differences in the length of rotations (three and four years respectively), the comparison of the farming systems refers to average values for a mean year of each crop rotation. The reliability of the results at this level is investigated afterwards by comparing mean values of all crops between years and by comparing different cultivated crops.

Energy Input

Though considerable relative reductions of the energy input are achievable in some input groups of the integrated systems (*Table 4*), the absolute energy savings were most important in the group 'N-fertiliser', followed by fuel and pesticide use. The energy input for machinery was higher in the integrated systems because of less optimal conditions of depreciation compared to the conventional systems. The last result depends on the applied allocation rules

(*Table 4*). Other energy inputs depend directly on the amount of yield (electricity use and basic fertilisation). Therefore, they were only indirectly influenced by changes in the farming systems.

Table 4: Energy use profiles [MJ (ha a)$^{-1}$] of the 'Conventional' farming systems and differences in energy input of the integrated systems compared to 'Conventional', mean years of rotations, two different locations

	Groups of supplies							
	Fuel, motor oil	Elec- tricity	Machi- nery	Seeds	Basic fertiliser	N- fertiliser	Pesti- cides	Total
Location Reinshof								
Harvest 1990-94								
Conv I	*2991*	*353*	*2712*	*408*	*2399*	*7684*	*895*	*17442*
Int	-489	-77	188	184	-281	-3320	-716	-4511
Harvest 1995-98								
Conv II	*2925*	*326*	*2734*	*400*	*2551*	*7017*	*521*	*16474*
Conv II[a]	-66	-27	22	-8	152	-668	-373	-968
Int-a[b]	-565	-98	221	-118	-599	-3641	-373	-5174
Int-a[c]	-158	-21	774	-32	-121	-2516	-323	-2398
Int-b[b]	-1390	-107	31	-109	-630	-3659	-151	-6015
Int-b[c]	-1082	-34	649	-20	-162	-2540	-27	-3217
Location Marienstein								
Harvest 1990-94								
Conv I	*2711*	*307*	*2685*	*410*	*2203*	*9094*	*789*	*18201*
Int	-416	-87	91	178	-450	-3350	-441	-4475
Harvest 1995-98								
Conv II	*2713*	*306*	*2630*	*415*	*2442*	*8373*	*628*	*17506*
Conv II[a]	1	-1	-55	5	238	-721	-162	-695
Int-a[b]	-371	-104	288	-127	-679	-4142	-433	-5567
Int-a[c]	45	-36	816	-46	-263	-2732	-368	-2584
Int-b[b]	-1192	-118	184	-121	-728	-3971	-178	-6123
Int-b[c]	-898	-56	779	-38	-329	-2504	-28	-3072

Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'

[a] Energy input difference in comparison to Conv I

[b] Annual set aside included in rotation (n= 4)

[c] Only productive crops, annual set aside not taken in account (n= 3)

The total area related energy savings in the 'Integrated' systems of the first project period [MJ (ha a)$^{-1}$] amounted to 25,9 % and 24,6 % (*Reinshof* and *Marienstein* resp.) compared to the references (*Table 4*). In the second project period the saved area related energy in 'Integrated flexible' amounted to 31,4 % and 31,8 % (*Reinshof* and *Marienstein* resp.). 'Integrated without plough' was even slightly better (36,5 % and 35,0 %

resp.). If annual set aside is excluded, the advantages in energy use for the integrated systems in the second project period are much smaller (*Table 4*, lower lines Int-a, Int-b). Furthermore the energy input in the reference systems of the second project period became slightly lower (-5,6 % *Reinshof*, -3,8 % *Marienstein* resp.; *Table 4*). That was affected mainly by a lower amount and changes in the applied types of N-fertilisers (introduction of ammonia sulphate) and by lower mean yields. The ranking of the systems according to the area related energy use for mean years on rotation level is found to be very stable over all investigated years (*Fig. 1*). 'Integrated flexible' and 'Integrated without plough' were similar; though in most years the latter had the lowest energy input on both sites.

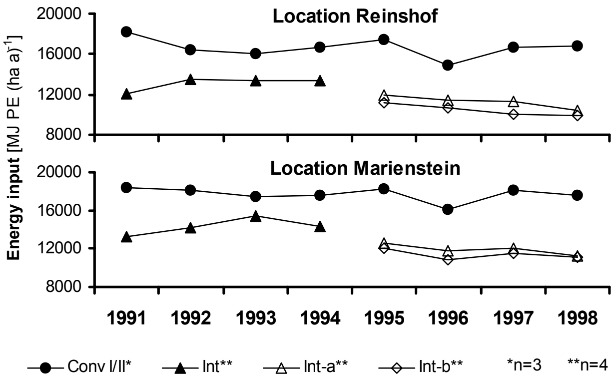

Fig. 1: Energy use [MJ (ha a)$^{-1}$] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'; n=number of crops)

Total area related energy input showed considerable differences between locations and crops. As a tendency, it was higher at location *Marienstein* (*Table 5*). Most crops had a higher demand of energy in the reference systems than in the integrated systems compared. *Table 5* shows a lower energy use per ha for 'Integrated without plough' than for 'Integrated flexible' for the majority of crops. Oil seed rape, winter wheat and winter barley can be labelled as energy intensive crops, whereas oats and field beans often need only little more than half of the energy input of these crops (*Table 5*).

Table 5: Mean total energy use [MJ (ha a)$^{-1}$] for all cultivated crops in the 'Conventional' and integrated systems, two different locations

	Crops					
	Rape seed	Winter wheat	Winter barley	Oats	Field beans	Ann. set aside
Location Reinshof						
Harvest 1990-94						
Conv I	17147	18651	16528	-	-	-
Int	15564	14534	12846	-	8780	-
Harvest 1995-98						
Conv II	15245	17552	16624	-	-	-
Int-a	15951	17467	-	8809	-	2973
Int-b	15398	16234	-	8138	-	2063
Location Marienstein						
Harvest 1990-94						
Conv I	17313	19487	17802	-	-	-
Int	16315	16023	15063	-	7501	-
Harvest 1995-98						
Conv II	16211	19133	17174	-	-	-
Int-a	15549	18339	-	10880	-	2989
Int-b	15873	17508	-	9921	-	2230

Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'

Energy Intensity

Energy intensity of single crops (*Table 6*) was expressed as [MJ t dry matter^{-1}]. For investigations of energy intensity of whole crop rotations, energy had to be aggregated as input per grain unit [MJ GU^{-1}]. GU is a German unit defined before the second world war for standardised evaluation of different agricultural products, based on starch units, crude protein contents and on their net energy (cereals: 10 GU t^{-1}; oil seed rape: 20 GU t^{-1}; field beans: 12 GU t^{-1}). By this way GU also takes into account differences in nutritional values. To get the same relation in energy intensity for single crops (MJ GU^{-1}), the figures in *Table 6* have to be divided by the factors indicated above and by the corresponding standard dry matter contents (see *Table 3*). All crop yield were corrected beforehand by the input of seeds for the main crops.

In energy intensity, only some tendencies could be identified for the ranking of systems, because each location had its own profile. Under good farming conditions (*Reinshof*) the integrated systems were often in the same range of specific energy use [MJ GU^{-1}] as the reference systems, or below them. Under less favourable farming conditions (*Marienstein*) the ranking changed annually, between the integrated systems as well as between ‚Conventional' and ‚Integrated' in general (*Fig. 2*). It is obvious that at this site the yields of the farming systems were more sensible to the annual natural conditions than at *Reinshof*. However, in the first cropping period at *Marienstein* (1990-94) the specific energy use in the system ‚Integrated' seems to be generally higher than ‚Conventional' (*Fig. 2*).

Table 6: Mean energy intensity of all crops [MJ (t dry matter)$^{-1}$] and of crop rotations [MJ GU^{-1}], conventional and integrated systems, two different locations

		Crops					**Rotations**
	n	Rape seed	Winter wheat	Winter barley	Oats	Field beans	Mean values
Location Reinshof							
Harvest 1990-94							
Conv I	3	4627	1916	1992	-	-	206
Int	4	4101	1872	1826	-	2159	190
Harvest 1995-98							
Conv II	3	4347	1967	2173	-	-	210
Int-a	4	4211	2167	-	1273	-	200[a]
Int-b	4	4111	2012	-	1313	-	192[a]
Location Marienstein							
Harvest 1990-94							
Conv I	3	4426	2356	2657	-	-	240
Int	4	5796	2441	2378	-	3176	257
Harvest 1995-98							
Conv II	3	4907	2209	2509	-	-	237
Int-a	4	6034	2301	-	1800	-	249[a]
Int-b	4	5476	2312	-	2021	-	249[a]

Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'; n= number of crops in rotation

[a] Annual set aside included in rotation (n= 4)

In contrast to the area related results, energy intensity for winter wheat in the second period was lower in the conventional systems, due to the higher yields. However, it remained higher for oil seed rape in this system at location *Reinshof*, where the mean yield was sometimes higher in the integrated systems (*Table 6*). Furthermore, oil seed rape at *Reinshof* always needed more than twice the energy input for one tonne of yield than the most intensive cereals winter wheat and it was even higher in *Marienstein*. The extensive crop oats was identified as the most energy efficient one at both locations, because cultivated after oil seed rape had a very low demand for N-fertilisation (*Table 6*). However, for all crops, the specific energy input in *Marienstein* was generally higher than in *Reinshof*, due to the lower yields and to a higher specific intensity of cropping in most crops at this site.

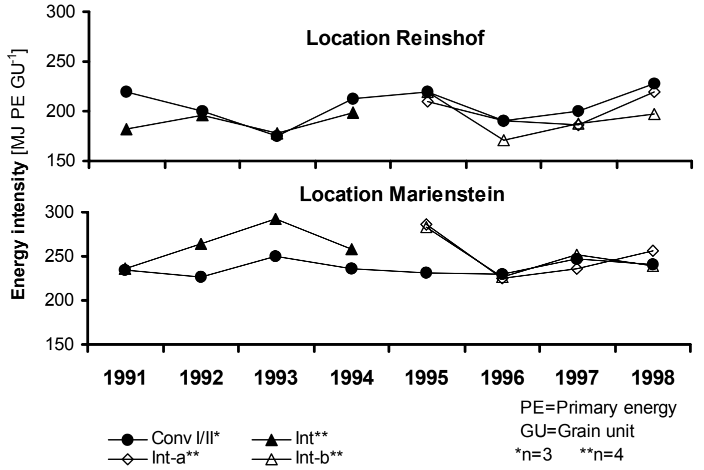

Fig. 2: Energy intensity [MJ GU^{-1}] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'; n= number of crops)

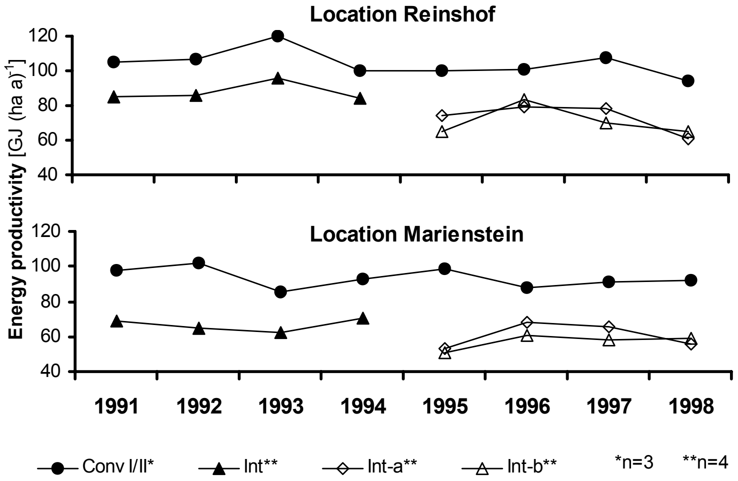

Fig. 3: Energy productivity [GJ (ha a)$^{-1}$] in the conventional and the integrated systems, each year mean values of all crops in the crop rotations, two different locations, annual set aside included (Conv= 'Conventional'; Int= 'Integrated'; Int-a= 'Integrated flexible'; Int-b= 'Integrated without plough'; n= number of crops)

Energy Productivity

As *Fig. 3* shows, energy productivity (=net energy yield; [GJ (ha a)$^{-1}$]) was higher at location *Reinshof* than at the less favourable location *Marienstein*; for a mean year of rotation almost 20 GJ (ha a)$^{-1}$.

Due to their high yields, the reference systems at *Reinshof* were capable of producing up to approximately 120 GJ (ha a)$^{-1}$ of mean net energy yield, whereas the integrated systems always had net energy outputs which were at minimum 20 GJ (ha a)$^{-1}$ lower than ‚Conventional‘, provided annual set aside was included (*Fig. 3* and *Table 7*). Comparable values for the systems Int-a and Int-b taking in account only the productive crops can be calculated from the givings in *Table 5* and *Table 7*. They show much smaller deviations from the reference systems.

Table 7: Mean net energy yield [GJ GE (ha a)$^{-1}$] of all crops and of crop rotations, conventional and integrated systems, two different locations

		Crops					Rotations
	n	Rape seed	Winter wheat	Winter barley	Oats	Field beans	Mean values
Location Reinshof							
Harvest 1990-94							
Conv I	3	78,15	135,03	114,45	-	-	109,21
Int	4	82,05	107,94	98,22	-	57,20	86,35
Harvest 1995-98							
Conv II	3	74,94	123,33	104,16	-	-	100,81
Int-a	4	81,46	109,81	-	103,98	-	73,06[a]
Int-b	4	80,93	111,15	-	92,95	-	70,73[a]
Location Marienstein							
Harvest 1990-94							
Conv I	3	83,29	111,11	87,95	-	-	94,12
Int	4	56,08	87,51	84,92	-	30,48	64,75
Harvest 1995-98							
Conv II	3	68,75	117,61	90,89	-	-	92,42
Int-a	4	50,72	107,46	-	87,64	-	60,69[a]
Int-b	4	58,67	102,03	-	70,10	-	57,13[a]

Conv= ‘Conventional’; Int= ‘Integrated’; Int-a= ‘Integrated flexible’; Int-b= ‘Integrated without plough’; n= number of crops in rotation

[a] Annual set aside included in rotation (n= 4)

Comparing single crops between the cropping systems, the net energy yield of the integrated oil seed rape at *Reinshof* was almost the same (Int) or higher than in the reference system (Int-a, Int-b resp.). In *Marienstein*, the reference system remained the most favourable one in both project periods (*Table 7*). The cereals in the integrated systems were not competitive with their conventional counterparts, except oats which – for comparison - must be seen as the integrated substitute for winter barley in the reference system of the second project period. Consequentely, the mean annual net energy yield in most cases remained below the reference rotation, even if the annual set aside of the second project period was excluded in the calculation of the integrated systems. Between the systems 'Integrated flexible' and 'Integrated without plough' only some slight preferences for the first are found (*Marienstein*), though at both locations no clear ranking for all years was identified (*Fig. 3*).

SOME POINTS OF DISCUSSION

Methodical Approach of Energy Accounting

Energy calculations always include some degree of uncertainty. Absolute figures can be substancially influenced

- by the energy coefficients used
- by the algorithms applied to estimate quantities for substance flows not measured, e.g. the specific fuel use of each work
- by details of the system boundaries, such as substance flows or processes which were excluded by definition

Therefore, a framework for comparisons with other results must be carefully prepared. The ranking of the farming systems in the investigated energy criteria is in general not influenced by changes in the underlaying energy coefficients. The used cropping data were calculated with five alternative energy data sets from other studies without major differences in the general system ranking (MOERSCHNER 2000).

When the gross energy incorporated in the seeds is subtracted from the total energy yield, as suggested in this study, the related substance and energy flows don't have the same physical basis. This causes some problems in terms of LCA-methodology. This way of calculation was chosen for better comparison with other energy studies on the input side. When data for LCA-applications should be provided, it may be a better solution to include the inherent energy of seeds into the energy coefficients used and indicate the share of incorporated solar energy and process energy. However, in the presented energy analysis the relations between the systems are not sensitive to such a change.

Machinery is often excluded in energy use studies of farming systems. In economic interpretations, capital goods are counted as fixed costs that are not included in gross margins. In this case study machinery was included because changes in cultivation intensity also cause impacts on the annual intensity in farm machinery use on a given area. As consequence, a reduced cultivation intensity should result in a reduction of applied farm machinery as well, because otherwise, their depreciation becomes an important energetical load within total energy budgets (MOERSCHNER 2000).

Background of Results and Critical View on the Way of Their Presentation

The reduction in energy use for N-fertilisation in the rotations of the integrated systems had the greatest impact on the results of the first project period. This reduction was first of all due to the low input crop field beans. Furthermore a site specific flexible reduction in overall cropping intensity can be stated (*Table 5*). In the second project period the introduction of oats into the integrated rotations was most successful in reducing the total energy input in comparison to 'Conventional'. This crop conserved great parts of the nitrogen left in the soil by the preceding crop oil seed rape after harvest with the positive consequence, that the highly energy consuming N-fertilisation for oats was reduced nearly until zero. Furthermore only very few pesticides were spread in this crop.

Annual set aside in the fourth year of the crop rotations of the integrated systems caused further important reductions of the mean area related energy input [MJ $(\text{ha a})^{-1}$]. They were accompanied by a considerable reduction in mean energy intensity [MJ GU^{-1}] and - as a negative aspect – by a reduction in mean energy productivity [GJ $(\text{ha a})^{-1}$] of the integrated rotations.

The decision to include the annual set aside into the integrated rotations was a result of a policy choice. Annual set aside was not essential for running the integrated farming systems. However, it certainly had positive ecological effects on the other crops, too. Therefore, it appeared to be one comprehensive way of analysis to generally include the annual set aside into the comparisons on rotation level.

Grain units (GU) were used for aggregated considerations of energy intensity. By this means only, whole rotations could be analysed in their energy intensity. The impacts of the integrated systems on gross margins have been the subject of other investigations and thus were excluded from the argumentation in this paper (see materials and methods).

CONCLUSIONS

Reductions in production intensity can be better established under good farming conditions as represented by the location *Reinshof*. The losses in productivity observed at *Marienstein* were higher. The observed negative impact of annual set aside (Int-a, Int-b resp.) in this context might be reduced by replacing set aside by a productive crop. The design of the new rotation seems to be a key issue among all factors determining energy saving through changes in the farming system.

The energy analysis has shown, that a site specific flexible reduction in farming intensity, depending on local natural conditions can open interesting potentials for saving (fossil) energy resources and at same time provides additional ecological advantages.

The interpretation of diesel fuel energy input finally demonstrates - besides possible savings when using reduced soil cultivation practices - the potentials for the introduction of more sustainable energy sources like biodiesel.

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