Energy use efficiency of organic and agroforestry farming systems

Lin, H.C.[1], Huber, J.[1] und Hülsbergen, K.-J.[1]

Keywords: Energy balance, energy use efficiency, wheat production, farming systems

Abstract

Im Versuchsbetrieb Scheyern (Süddeutschland) wurde in Feldexperimenten die Energienutzungseffizienz (EUE) ökologischer Anbausysteme analysiert. Die EUE wurde für verschiedene Systemebenen - die Fruchtarten, die Fruchtfolge sowie Agroforstsysteme (AFS) bestimmt. Die Agroforstsysteme bestehen aus Baumreihen mit schnellwachsenden Gehölzen zur energetischen Nutzung sowie einer Fruchtfolge zur Nahrungserzeugung. Die EUE entspricht dem Verhältnis von Energieoutput zum Energieinput. Der Energieinput umfasst den Einsatz fossiler Energie, der Energieoutput den Brennwert der Ernteprodukte.

Die EUE von Weizen wird stark von der Vorfrucht beeinflusst; sie beträgt nach Kartoffeln 10,1, nach Luzerne-Kleegras 19,5, im AFS 9,7 (nach Kartoffeln) und 18,8 (nach Luzerne-Kleegras).Die Energienutzungseffizienz der Fruchtfolge beträgt 10,3, die des Agroforstsystems 12,8.

Introduction and objective

Energy is an important input in agricultural farming systems. Energy is used in two ways: direct energy inputs such as fuel and electricity for machinery operation on farm level, and indirect energy inputs by fertilizer, pesticide, and machinery production for the farm. Fossil energy is known as limited resource, great contributor to greenhouse gas emissions, and indicator for production intensity and intervention in agro-ecosystems. It is necessary to manage this resource in an efficient way.

Agroforestry is a farming system consisting of trees and crops. It is believed to be beneficial for soil fertility, use of water, and erosion protection. Several publications compared energy balances and greenhouse gas balances of organic and conventional farming systems, but rarely these assessments included options with agroforestry (Tuomisto et al. 2012). This study aims at clarifying the energy use efficiency (EUE) of agroforestry and comparing it with an organic farming system.

Methodology

a) Experimental site

Data recorded in the experimental farm Scheyern were used for this analysis. Scheyern is located in Southern Germany, 40 km north of Munich, 445 to 498 m above sea level in a hilly landscape. The average precipitation and temperature is 833 mm and 7.4 °C, respectively. The soil type can be characterized as loamy to sandy cambisols

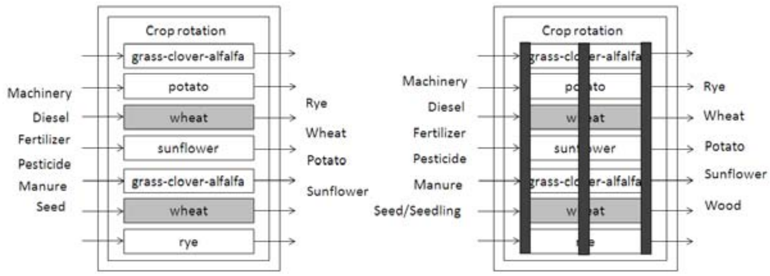
[1] Lehrstuhl für Ökologischen Landbau und Pflanzenbausysteme, Technische Universität München, Alte Akademie 12, 85350 Freising, Deutschland, hc.lin@mytum.de, http://www.wzw.tum.de/oekolandbau/.

Dieser Beitrag ist im Tagungsband der 12. Wissenschaftstagung Ökologischer Landbau erschienen.
D. Neuhoff, C. Stumm, S. Ziegler, G. Rahmann, U. Hamm & U. Köpke (Hrsg.) (2013):
Ideal und Wirklichkeit - Perspektiven Ökologischer Landbewirtschaftung.
Beiträge zur 12. Wissenschaftstagung Ökologischer Landbau, Bonn, 5. - 8. März 2013
Verlag Dr. Köster, Berlin.
Der Tagungsband kann über den Verlag Dr. Köster bezogen werden.
Archiviert unter: http://orgprints.org/view/projects/int-conf-wita-2013.html

derived from tertiary sediments partly covered by loess (Küstermann et al. 2008). This farm has implemented organic farming systems for more than 20 years, and has started agroforestry in 2009.

b) System boundary and modeling approach

To analyze EUE, all the fossil energy inputs need to be defined. The system boundary of each farming system is shown in Figure 1. All the energetic analysis were made at field level, which means the post-harvesting processes such as transportation of products are not included. The analyzing energy balancing method is referred to Hülsbergen et al. (2001). The relevant energy equivalents are: 39.6 MJ l^{-1} for diesel fuel; 108 MJ kg^{-1} for machinery (production, maintenance, and repair); 5.7, 6.5, 6.5, 12.0, and 15.0 MJ kg^{-1} for seed of potato, wheat, rye, sunflower (REPRO) and tree seedling (Schmidt, unpublished result). The calorific value of harvested biomass is counted as energy output. These values are 17.2, 18.6, 18.6, and 26.8 MJ/kg for potato, wheat, rye, and sunflower (Hülsbergen 2003); 20, 19, 19, and 22 MJ/kg for poplar, willow, alder, and black locust (Klasnja et al. 2002, Nurmi 1997, Klasnja et al. 1999).



a. Organic farming system b. Agroforestry system

Figure 1: Structure, inputs and outputs of the farming systems. There are 6 tree rows in a total width 8.25 m and arable land in width 30 m in agroforestry system, the share of forest and arable land is therefore 21.5% and 78.5%, respectively. The black stripes in Figure 1b represent the tree rows.

Data of production processes and yields of the systems were averaged from 2009 to 2012. The yield of agricultural subsystem in agroforestry was assumed to be the same as in organic farming system. We found positive interactions between trees and crops, but also negative yield effects (competitions for water, solar radiation, and nutrients). Interactions between trees and crops are going to be measured and assessments have already started with the yield analysis using sensor technology (Ochsenbauer 2012). The results will be compared with the current assumption. Furthermore, because the agroforestry system was established in 2009, the trees are still small; the interactions between trees and crops are not yet obvious, which means the yield of crops should not be highly influenced yet, too. The yield of trees in agroforestry system is from measured data in Scheyern.

The energy inputs from diesel and machinery in agroforestry is assumed to be five percent higher than in organic farming system according to Fröba et al. (2005). The machinery operated area in agroforestry is separated by trees as shown in Figure 1.

The crop rotation is grass-clover-alfalfa, potato, wheat, sunflower, grass-clover-alfalfa, wheat, rye. Grass-clover-alfalfa was not harvested; there is no energy output from it

Dieser Beitrag ist im Tagungsband der 12. Wissenschaftstagung Ökologischer Landbau erschienen.
D. Neuhoff, C. Stumm, S. Ziegler, G. Rahmann, U. Hamm & U. Köpke (Hrsg.) (2013):
Ideal und Wirklichkeit - Perspektiven Ökologischer Landbewirtschaftung.
Beiträge zur 12. Wissenschaftstagung Ökologischer Landbau, Bonn, 5. - 8. März 2013
Verlag Dr. Köster, Berlin.
Der Tagungsband kann über den Verlag Dr. Köster bezogen werden.
Archiviert unter: http://orgprints.org/view/projects/int-conf-wita-2013.html

hence. The tree species included in the agroforestry system are poplar, willow, alder, and black locust. These four species have the same share of forest area, and the total share of forest area is 21.5%. They are assumed to be harvested three years after plantation. The energy input of recultivation (e.g. soil tillage) of forestry system after an expected 20-year production period was considered in this study.

Results and discussion

Results of organic farming system are shown in Table 1. The EUE of organic wheat is 10.1 (wheat after potato) and 19.5 (wheat after grass-clover-alfalfa); the EUE of the crop rotation is 10.3. The agroforestry system has a similar EUE, which is 9.7, 18.8, and 10.1 for wheat after potato, wheat after grass-clover-alfalfa, and the whole crop rotation. The EUE of the forestry subsystem and the whole agroforestry system is 23.0 and 12.8, respectively (Table 2).

Table 1: Energy balance of the organic crop rotation.

	Direct energy input (GJ ha^{-1})	Indirect energy input (GJ ha^{-1})	Energy input (GJ ha^{-1})	Yield (Mg-DM ha^{-1})	Energy output (GJ ha^{-1})	EUE
Grass-clover-alfalfa	2.3	0.8	3.1	*	*	*
Potato	4.8	5.1	9.8	6.0	104.0	10.6
Wheat	3.1	1.4	4.6	2.5	46.0	10.1
Sunflower	3.6	1.6	5.2	2.6	70.0	13.5
Grass-clover-alfalfa	1.5	0.7	2.2	*	*	*
Wheat	2.0	1.1	3.1	3.2	59.9	19.5
Rye	2.2	1.3	3.5	3.0	55.5	15.8
Crop rotation	2.9	1.8	4.6	2.5	47.9	10.3

*Grass-clover-alfalfa was left in the field as green manure.

Grass-clover-alfalfa is known for its nitrogen-fixation ability; this nitrogen is partially transferred to the following crops. Compared with wheat after potato, wheat after grass-clover-alfalfa has better nitrogen availability. Grass-clover-alfalfa is not harvested in this study. This is a typical situation in organic arable farming system without animal husbandry. In a mixed organic farming system, grass-clover-alfalfa is commonly harvested as fodder. The potential energy output of grass-clover-alfalfa is relatively high and could make the EUE of crop rotation in a mixed organic farming system higher (Küstermann et al. 2008).

The forestry subsystem is analyzed after a three-year-cultivation period (2009 to 2011). Table 2 shows the averaged energy input of the forestry subsystem. Most of the energy input is from the first year and is used for establishing the system. The energy input in the following years is much less. The yield of forestry subsystem is the lowest in the first year, but increasing with time. Therefore, the length of cultivation period may have an influence on EUE. There might be an underestimate of EUE of forestry subsystem as well as agroforestry system in this study.

Dieser Beitrag ist im Tagungsband der 12. Wissenschaftstagung Ökologischer Landbau erschienen.
D. Neuhoff, C. Stumm, S. Ziegler, G. Rahmann, U. Hamm & U. Köpke (Hrsg.) (2013):
Ideal und Wirklichkeit - Perspektiven Ökologischer Landbewirtschaftung.
Beiträge zur 12. Wissenschaftstagung Ökologischer Landbau, Bonn, 5. - 8. März 2013
Verlag Dr. Köster, Berlin.
Der Tagungsband kann über den Verlag Dr. Köster bezogen werden.
Archiviert unter: http://orgprints.org/view/projects/int-conf-wita-2013.html

Table 2: Energy balance of the agroforestry system.

	Direct energy input (GJ ha^{-1})	Indirect energy input (GJ ha^{-1})	Energy input (GJ ha^{-1})	Yield (Mg-DM ha^{-1})	Energy output (GJ ha^{-1})	EUE
A) Agricultural subsystem						
Grass-clover-alfalfa	2.4	0.9	3.3			
Potato	5.0	5.2	10.2	6.0	104.0	10.2
Wheat	3.3	1.4	4.7	2.5	46.0	9.7
Sunflower	3.7	1.7	5.4	2.6	70.0	13.0
Grass-clover-alfalfa	1.6	0.7	2.3			
Wheat	2.1	1.1	3.2	3.2	59.9	18.8
Rye	2.4	1.3	3.6	3.0	55.5	15.2
Crop rotation	3.0	1.8	4.8	2.5	47.9	10.0
B) Forestry subsystem						
Forestry	2.5	2.4	4.9	5.4	111.3	23.0
Poplar				6.4	128.7	
Willow				4.0	75.4	
Alder				4.7	88.7	
Black locust				6.6	152.6	
C) Agroforestry	2.9	1.9	4.8	4.8	61.6	12.8

Conclusion

The implementation of agroforestry systems has only small effects on the EUE. One of the reasons is the agroforestry system was introduced to Scheyern since 2009, the forestry subsystem is not yet well-developed to have significant interactions with crops. Wheat after grass-clover-alfalfa has a higher yield compared with wheat after potato because of the nitrogen transfer. Grass-clover-alfalfa in this study is not harvested. If it is harvested and taken the energy output into account, there is potential to increase the EUE of both the farming systems.

Reference

Fröba N., Funk M. (2005): Dieselkraftstoffbedarf bei landwirtschaftlichen Arbeiten. Kuratorium für Technik und bauwesen in der Landwirtschaft e. V., Darmstadt

Hülsbergen K.-J. (2003): Entwicklung und Anwendung eines Bilanzierungsmodells zur Bewertung der Nachhaltigkeit landwirtschaftlicher Systeme. Shaker Verlag Aachen.

Hülsbergen K.-J., Feil B., Biermann S., Rathke G.-W., Kalk W.-D., Diepenbrock W. (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.

Klasnja B., Kopitivic S. (1999): Quality of wood of some willow and robinia clones as fuelwood. Wood Res 44: 9-18.

Klasnja B., Kopitivic S., Orlovic S. (2002): Wood and bark of some poplar and willow clones as fuelwood. Biomass and Bioenergy 23: 427-432.

Küstermann B., Kainz M., Hülsbergen K.-J. (2008): Modeling carbon cycles and estimation of greenhouse gas emission from organic and conventional farming systems. Renewable Agriculture and Food System 23: 38-52.

Nurmi J. (1997): Heating values of mature trees. Acta Forestalia Fennica 256: 1-28.

Ochsenbauer M. (2012): Quantifizierung der räumlichen Wachstumsvariabilität von Winterweizen in einem silvoarablen Agroforstsystem auf Grundlage von Spektralanalysen. Masterarbeit, Technische Universität München.

Tuomisto H.L., Hodge I.D., Riordan P., Macdonald D.W. (2012): Comparing energy balances, greenhouse gas balances and biodiversity impacts of contrasting farming systems with alternative land uses. Agricultural Systems 108: 42-49.

Dieser Beitrag ist im Tagungsband der 12. Wissenschaftstagung Ökologischer Landbau erschienen.
D. Neuhoff, C. Stumm, S. Ziegler, G. Rahmann, U. Hamm & U. Köpke (Hrsg.) (2013):
Ideal und Wirklichkeit - Perspektiven Ökologischer Landbewirtschaftung.
Beiträge zur 12. Wissenschaftstagung Ökologischer Landbau, Bonn, 5. - 8. März 2013
Verlag Dr. Köster, Berlin.
Der Tagungsband kann über den Verlag Dr. Köster bezogen werden.
Archiviert unter: http://orgprints.org/view/projects/int-conf-wita-2013.html