Enhancing GHG balances in organic farms by integration of new bio-energy crop concepts

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Summary

Chances to increase the efficiency of the plant production of organic farms by increasing of land equivalent ratios (LER), yield advances by nutrient recycling and the use of typical by-products of organic production in bio-energy cropping concepts are described. Mixed cropping with oil crops and the integration of hedges offer chances to increase land use efficiency, decrease GHG emissions and to simultaneously uphold food production.

Key words: renewable energy, mixed cropping, oil crops, agroforestry, biogas, resource efficiency

Increasing site resource efficiency

Typically low product-bound climate efficiency values in organic farms can be enhanced by yield increases, reduction of energy input or the integration of the production and use of renewable energy (RE) sources. Especially the integration of bio-energy crops offers interesting chances to increase the efficiency of the plant production of organic farms.

If production lines are increasingly integrating pure biomass production, e.g., for biogas production, cultures with multiple harvests per year, like clover grass, can rise in economic value. Also, special multiple harvest crop sequences over the year can be designed for an effective use of site and climatic resources, e.g., winter peas followed by maize (Grass and Scheffer, 2003) or winter cereals followed by maize followed by cereal-pea GPS (Deublein and Steinhauser, 2008). In the field of biomass production and breeding, plant selection on light sensitivity and especially the transfer of plants adapted to short day into long day conditions is promising for enhancing biomass production on short call (Camus-Kulandaivelu et al., 2006, Markelz et al., 2003). Site resources are still yield-limiting in these production lines, but sequences of different plant types can use them more efficient. So a sequence of C3 (cold resistant) and C4 plants (drought and heat effective) addresses water and heat conditions in different times of the year (Deublein and Steinhauser, 2008).

In biomass production, the increased introduction of mixed cropping systems can be expected. More yield stability and positive effects on resource efficiency are described. Different rooting depths and architecture, and different periods of biomass development in mixed cropping systems can efficiently increase the use of available resources and might increase area productivity. Land equivalent ratios (LER) (Mead and Willey, 1980) are frequently raised in those systems (Tentbarth, 1986).

Direct effects on resource efficiency and yields can be anticipated by targeted recycling of plant nutrients from the processes of bio-energy generation. Biogas slurry as mobile plant nutrient source and fertiliser can help in overcoming spatial and temporal nutrient deficiencies (Moeller et al., 2006). Also ashes from biomass combustion (Uckert, 2004, Eichler-Löbermann, 2006), and oil-cakes from vegetable oil production are area-independent mobile sources of plant nutrients for base fertilisation (Tab. 1). Effects on the GHG balance are to be expected by the replacement of other mineral fertilizers, and by probable increase or stabilisation of yield levels.

Table 1: Examples of mean nutrient contents of different residues of bio-energy production [kg t^{-1} fresh matter]

	DM [%]	pH	N_{tot}	NH_4-N	P	K	Mg	Ca	
Biogas slurry	3-4	7.9-8.1	2.6-3.7	1.3-2.2	0.4-0.6	1.8-2.6	0.3-0.4	1.0-1.2	1
Combustion ashes									
straw	97-99	10.5-11.5	1.3		8-10	97-119	20-26	42-56	2
wood	97-99	12-13	<1		4-11	53-63	17-36	230-298	2
oilcake	99				79	73	54		3
Oilcake	90		43-48		8-10	10-13	3-4	4-6	4

[1]Poetsch et al., 2004 [2]Odernberger 1997 [3]Schiemenz 2007 (unpublished data University Rostock) [4]own analyses (oilcakes of rapeseed, linseed, false flax)

Cropping concepts for oil seeds

The supply of farm-produced renewable fuel for machinery can be secured with pure vegetable oils in special adapted tractors (Voegelin, 2006, Paulsen and Schaedlich, 2005). The replacement of diesel fuel by pure rapeseed oil today is seen as the cheapest and available technology in the area of bio-fuels if the costs for CO_2-reduction are considered (SRU, 2007). Fuel-quality standards are developed (DIN V 51605) for pure rapeseed oil. The use of other vegetable oils as fuel has not been consequently assessed and is far from standardisation, but vegetable oil mixtures (of mustard oil, soy bean oil and rapeseed oil) are oriented at the quality values given in the DIN V 51605 and are sold as vegetable oils fulfilling the DIN standards for fuel purposes. In an actual scientific research project, mixtures of oil from false flax (*Camelina sativa spp.)* and other vegetable oils are characterized and proofed in laboratory and field engines (FNR, 2007).

Oil crops in mixed cropping with grain legumes or cereals could contribute 100-300 l ha^{-1} vegetable oil for purposes of renewable energy and simultaneously food production would be upheld. False flax showed high flexibility in most of the applied mixtures with spring seeds (Paulsen, 2007). Mustard and spring rape suppressed the partners in the mixtures and caused high yield losses in the main culture. Safflower dominated the mixtures with legumes and linseed was dominated by summer wheat. Still most LER values of the mixtures are indicating increases in resource efficiency (Paulsen and Schochow, 2007). Average oil yields of those mixtures could satisfy the average fuel demand for farmland that ranges between 90-150 kg ha^{-1} [Fig. 1]. But only the mixtures with false flax showed significant overproduction of vegetable oil measured by the average fuel demand and could contribute to the fuel demand of additional farmland.

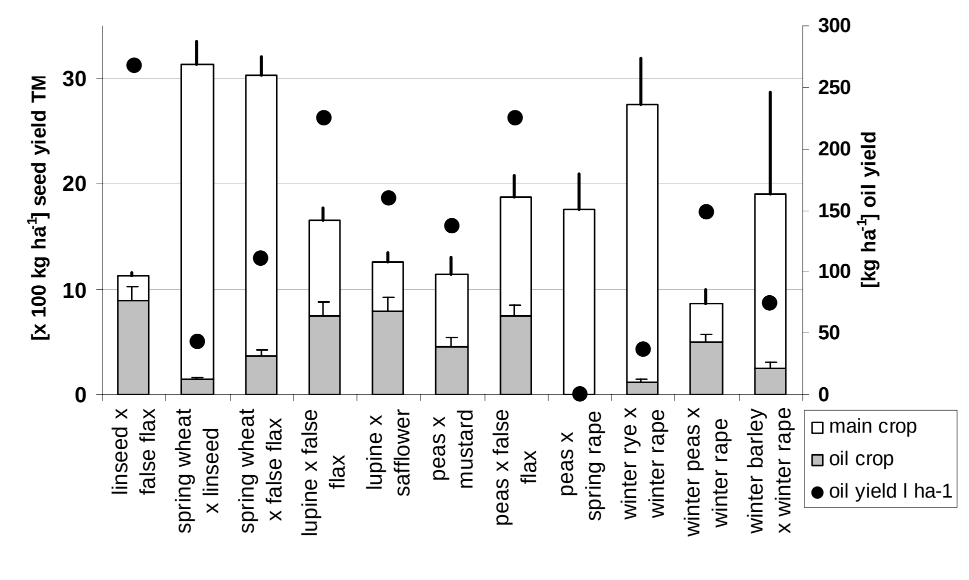

Fig. 1: Average grain yields of mixed cropping systems of different oilseeds with spring cereals and grain legumes [t ha^{-1}], oil yields of the oil crops in the mixtures

If the sowing of the different cultures is combined (Paulsen und Pscheidl 2007), only small additional GHG-emissions are to be expected in life-cycle-analyses due to the need for additional seeds, additional drilling technology, and grain separation. If yield losses in the main culture occur, the environmental costs have to be allocated to the mixed oil crop. On the other hand, better weed suppressing capacity of mixed cropping systems (Paulsen et al. 2006, Paulsen et al. 2007, Saucke and Ackermann, 2005) saves harrowing in the fields and contributes positively to GHG balances. Sergis-Christian and Brouwers (2005) estimated GHG-emissions for the cropping system with false flax and peas: CO_2 eq. emissions from false flax oil were 125 g per litre diesel fuel equivalent (Table 2). The estimation showed that this is only one third of the GHG-load of the production of organic rape seed oil. If the oilcake (amount=7/3*oil yield) were to be used additionally as source of renewable energy in digestion or combustion, the saving of GHG by replacement of fossil energy sources would increase further. Due to the ban of false flax products in animal feeding in the EU today (Directive 2002/32/EC) this would be one of the possible uses.
Table 2 shows the possible GHG reduction by the substitution of fossil fuel with the vegetable oil produced with the different cropping systems. Significant amounts of GHG emissions caused by the

cropping systems can be balanced. In case of the mixed cropping systems with false flax the reduction is over-proportional in comparison to possible yield losses in the main crop and higher than the additional GHG emissions for the mixed cropping system. The energetic use of oilcake is not considered and would increase GHG reduction further. Due to the higher oil yields in sole cropping systems with rapeseed or linseed and in the intensified fallow the substitution of fossil fuel and the GHG effect has higher values. If the oil would be used as fuel the oil cake, representing 70 % of the yield, is still available for use in livestock feeding.

Table 2: Green house gas (GHG) emissions of different cropping systems with oil crops; GHG-reduction through the production of vegetable oil as a substitute for diesel; yield losses for food and forage caused by the cropping system, and/or the use of vegetable oil as fuel and remaining food and forage yield

	Yield losses for food and forage [kg ha^{-1}]	Food and forage yield [kg ha^{-1}]	Vegetable oil yield [kg ha^{-1}] Substitution of fossil fuel [kg]	[a]GHG emissions cropping system CO_2 eq. [t $ha^{-1}a^{-1}$]	[c]GHG reduction by substitution of fossil fuel CO_2 eq. [t $ha^{-1}a^{-1}$]
Clover x rapeseed	*	700-1000 oilcake	300-500	0.6 + 2.9	1.1-1.9
Rapeseed	300-500 oil	700-1000 oilcake	300-500	2.9	1.1-1.9
Peas x false flax	0-200 peas	1500-4000 peas	130-240	3.4 + 0.02[b]	0.5-0.9
Wheat x false flax	200-500 wheat	30-45 wheat	60-120	3.0[d] + 0.02[b]	0.2-0.4
Linseed	280-450 oil	540-900 oilcake	280-450	*	1.0-1.7

[a]data from Nemecek et al. 2005, [b]15.6 kg ha^{-1} CO_2 eq. for additional input for false flax in mixed cropping (Sergis-Christian and Browers 2005), [c]diesel fuel: CO_2 eq. 313,6 g kwh^{-1}, heating value 11,83 kwh kg^{-1}, together 3711 g kg^{-1} CO_2 eq. (Fritsche and Schmidt 2007), [d]estimation: Mean of values for winter wheat 3.4 and spring barley 2.7, *no data available

Current trials on mixtures of winter rapeseed with winter cereals and winter legumes showed that those mixtures are difficult to establish. Yield advantages were not typical and land equivalent ratios showed values of about “one” in the applied mixtures (Paulsen and Schochow, 2007, Szumigalski and van Acker, 2005 and 2006). More promising are ideas to intensify the clover-fallow with rapeseed (Paulsen et al., 2003, Paulsen and Rahmann, 2004, Boehm, 2007). Undersown white clover proved to be a viable partner for rapeseed. Under a normal rapeseed development, the nutrient value of clover could be kept for the following fruit. This, and even the establishment of other oil crops like sunflower, safflower or mustard at the clover fallow could be a competitive alternative to sole cropping of oil crops or an enrichment of oil producing crop rotations in organic farming. Those intensified fallows could find their place in organic cash crop farms. In livestock farms, where the forage demand is typically satisfied by clover-grass, yields and quality of under sown clover grass mixtures after the harvest of the oil crop and must be evaluated.

For the research farm of the vTI Institute of Organic Farming in Trenthorst in north Germany, a crop rotation model with a combination of mixed cropping and pure rapeseed and linseed cultivation was fed with current yield data of large scale field cultivation and from plot trials. The crop rotation promises to deliver 100 kg pure vegetable oil per hectare arable land. It contains 20% of mixtures of grain legumes or cereals with false flax, 2% mustard with undersown clover as intensified green fallow, 7% rapeseed and 3.5% linseed in sole cropping and 3.5% linseed in mixed cropping with oats. Rapeseed (50%) and linseed (15%) would contribute 65 % to the vegetable oil production of that farm. 35 % of the oil are derived from mixed cropping systems with false flax or mustard. Current research on suitable vegetable oil mixtures to maintain the thresholds of the DIN standards for rape seed oil for fuel purposes, and focusses on oil mixtures from false flax and rapeseed in a ratio of 30 : 70. Due to the high yield risk of rapeseed the area for sole cropping is normally kept limited. Thinking on farms with fuel self sufficiency to the presented experiences on yield levels shows that the percentage of non-rapeseed oil in crop rotations and in vegetable oil mixtures used as fuel should be higher.

Agroforestry concepts

The increasing demand for, and profitability of, RE-sources could help organic farms to increase their production with site specific integration of short rotation coppices (SRC), e. g., at waterlogged marginal sites and areas or shady field borders. With this type of RE production, high biomass yields seem to be possible even at difficult site conditions. Poplar hybrids have a yearly yield potential of between 8 and 12 t ha^{-1} dry matter (Burger, 2004), willows, alder and aspen have lower yield potentials. The nutrient uptake of a yield range between 8 and 16 t ha^{-1} a^{-1} is reported with [kg ha^{-1} a^{-1}] N: 29-58, P: 5-10, K 22-45, Ca: 41-82, Mg 5-10 (Traupmann, 2004). Except for N the values are in the range of equivalent dry matter yields of cereals. The N demand seems to be lower. A significant yield increase by P/K-fertilisation for alder is reported by Joergensen (2005).
GHG-balances of the substitution of fossil fuels by SRC wood are very efficient in CO_2-reduction (Adler et al. 2007, Öko-Institut 2007). Additionally long term cultivation, soil covering and biomass production of SRC plantations will increase carbon stocks in soil and decrease GHG further (Burger, 2007). Even an increase in biodiversity of avi-fauna and flora is reported (Burger, 2006, SRU, 2007).
Difficult points of the introduction of SRC are long term binding of agricultural areas, loss of flexibility in crop rotations and high water demand. Ashes of burning processes should be recycled in fertilisation (Table 1) in adopted dosage (Zimmermann and Bundt, 2005, Pitman, 2006). Possible heavy metal contents in burning ashes can be reduced by the separation of finest ash fractions (Odernberger, 1997). Open are questions of pest and disease management in SRC (Tucker and Sage, 1999) in organic farming. For N-fertilisation leguminous trees (Joergensen et al. 2005) and undersown clover are discussed (Granhall 1995). No reports are available on experiences of weed management in organic SRC. Due to heavy yield reduction by high weed-competition during establishment (DEFRA 2002), organic farmers have to gain experiences in that field. GHG-balances and delivering costs will be determined by the transportation costs to the heat-power-plant (Hartmann and Strehler 1995).
A special form of the integration of SRC in farms would be the integration of hedges. Wind-breaking can have positive effects on soil moisture protection and wind erosion damages (Möndel, 2007, SMUL 2006), and could be combined with the production of RE wood as a source for local combustion plants. Silvo-arable forestry has potential to increase LER values on agricultural land and offers food and RE together. The results of the SAFE Project (Dupraz et al. 2005) reveal that agroforestry systems with stripes of arable land and forests have interesting yield potential in most European regions. Strict positive ecological effects can be anticipated: wind, soil moisture and erosion protection, offering of new habitats and food resources for natural fauna, increases in biodiversity, diversification of agricultural landscape (Surboeck et al., 2005, Schmelz, 2001). Due to the positive effects on biodiversity, the integration of hedges in agricultural production corresponds to the guidelines of organic production. Labour minimized harvest techniques (Holzer, 2007, DEFRA, 2002) and the relatively high yield potential under extensive nutrient conditions, makes the integration of SRC hedge systems in organic farms interesting. Other open questions are the effects on pests and disease occurrence, and on the development of natural predators (Kühne et al., 2006) as well as aspects of root, water and nutrient competition in the adjacent hedge area.

Integration of biogas

The use of biomass of fallows and cover crops - typical for organic production - for biogas production, offering mobile nitrogen sources for fertilisation, will have positive effects on yield-, nutrient- and GHG-efficiency (Möller et al., 2006). In cash crop farms the changing in legume management from mulch systems to harvest systems reduces N-losses and increases N-fixing of legumes (Loges et al., 2000, Ruhe et. al., 2003). Nevertheless increasing N-losses, erosion problems and bad economics are reported for specialized organic biogas farms (Helbig et al., 2007). In intensive livestock farms, changes in crop rotations were necessary to increase N-efficiencies when internal or external co-substrates were integrated in the biogas production (Möller et al., 2006). Those problems and even economical limits of small units could be met with conceptual participating of organic farmers on local biogas plants, ensuring optimal redistribution of nutrients and balanced N-supply. This is already described in scenarios for untreated animal manures (Dalgaard et al., 2005, Granstedt, 2000).

Discussion and conclusions

In organic farms, significant amounts of biomass are available as a source for renewable energy. Typical by-products of the farming system are clover grass and intercrops. Straw, as source for bio-energy, is generally named as main by-product from farming systems (SRU, 2007). The integration of short rotation coppices with possible synergistic effects on nature protection and landscape structure, and the intensified integration of oil crops for fuel purposes addresses the increasing demand for renewable energy sources. These new bio-energy crop concepts can additionally increase resource efficiency and reduce product bound GHG-emissions of organic farming. In Figure 2 the heating value of the average biomass, harvested in different organic crop rotations in the research farm of the Institute of Organic Farming (vTI) are calculated. An average fuel equivalent between 2800 and 4000 l ha^{-1} a^{-1} has been produced.

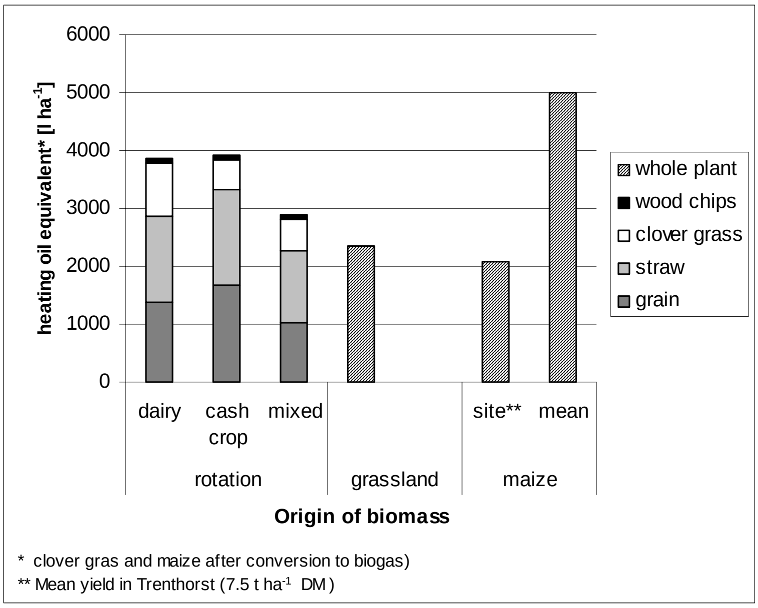

Fig. 2: Average yearly energy yield of plant materials grown in different organic crop rotations in comparison to the energy yield gained in organic maize production (yield data: Trenthorst 2003-2006, mean value for maize: variety trials 2006, German Maize-Committee, Bonn)

In this farm the residues straw, clover grass and wood from existing hedges cover round about 70 % of the total produced energy. Grassland offers an additional harvest of 2200 l ha^{-1} a^{-1}. The average yields of the residues and by products per hectare are nearly equivalent than the bad yield gained in the organic maize production on this site. Normal energy yields in organic variety trials range between 15-22 t ha^{-1} dry matter. But the residues for RE are not in competition with food production. The GHG-emissions of the equivalent fossil fuel combusting could be avoided by their consistent use. Utilisation of at least parts of these energy resources could be realistic goal in organic agriculture. An open question is, whether organic farms can satisfy and replace the nutrients and soil carbon under intensified use of residues and the desired yield increase of new cropping concepts. Another point is that only concepts integrating both the satisfaction of food demand and of bio-energy production (Table 2), are suitable to meet the demands of organic farming for the future.

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