Improving green-house gas balances of organic farms by the use of straight vegetable oil from mixed cropping as farm own fuel and its competition to food production

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Abstract

Mixed cropping is frequently used in organic farming and recommended worldwide in low external input areas to increase productivity, yield security and product diversity. In trials with different oil crops camelina (false flax, *Camelina sativa L.*), linseed (*Linum ustitatissivum L.*), rape (*Brassica napus L.*), safflower (*Carthamus tinctorius L.*) or white mustard (*Sinapis alba L.*) grown together with grain legumes or cereals on German sites the potential of renewable fuel production parallel to food production was evaluated in organic farming. Depending on the crop-combination between 10 to 900 kg/ha vegetable oil could be produced. This could cover the fuel demand of agricultural machinery for 0.1 to 9 ha farmland. The food crops combined with oil plants in mixed cropping mostly had relative yields higher as 0.5, showing that also yield increases in food production are possible parallel to the production of renewable fuel. As example for an introduction of a non-common oil crop in farm cycles, research results on the use of straight vegetable oil as fuel in tractors and of oil-cake as feedstuff for livestock from camelina are summarised. Based on the results the importance for the GHG emissions of organic farms is discussed. When mixed cropping systems with oil crops and the use of all products are consequently introduced, improvements in the GHG balance of farms can be expected by savings in production and yield stabilisation in mixed cropping as well as by direct substitution of diesel fuel in agricultural machinery and by substitution of imported feed components for livestock.

Keywords: Organic farming, feed components, food and biofuel, mixed cropping

Zusammenfassung

Verbesserung der Treibhausgasbilanzen ökologischer Betriebe durch die Nutzung von Pflanzenöl aus dem Mischfruchtanbau als hofeigenen Biokraftstoff und die Konkurrenz zur Nahrungsmittelproduktion

Mischfruchtanbau wird im Ökologischen Landbau und auch weltweit in Anbauregionen mit schlechtem Zugang zu externen Betriebsmitteln angewandt, um die Produktivität, Ertragssicherheit und die Produktionsvielfalt abzusichern und zu steigern. In Versuchen mit verschiedenen Ölfrüchten Leindotter *(Camelina sativa L.*), Öllein (*Linum ustitatissivum L.*), Raps (*Brassica napus L.*), Saflor (Färberdistel, *Carthamus tinctorius L.*) *oder* weißem Senf (*Sinapis alba L.*) im Mischfruchtanbau mit Körnerleguminosen oder Getreide in Deutschland wurde das Potential dieser Anbausysteme zur Biokraftstofferzeugung parallel zur Nahrungsmittelproduktion ermittelt. Abhängig von der Fruchtartenkombination konnten im Ökologischen Landbau so 10 bis 900 kg/ha Pflanzenöl erzeugt werden. Dies könnte den Treibstoffbedarf für die Bewirtschaftung von 0,1 bis 9 ha Land abdecken. Für die gleichzeitig produzierten Nahrungs- bzw. Futterpflanzen wurden überwiegend Relativerträge von größer als 0,5 ermittelt. Der Wert zeigt, dass neben der Erzeugung von Pflanzenöl, z. B. zur Nutzung als Biotreibstoff, auch Ertragssteigerungen bei den Nahrungspflanzen erzielt werden können. Als Beispiel für die Einführung einer Ölfrucht in den Kreislauf landwirtschaftlicher Betriebe werden Forschungsergebnisse zum Einsatz von reinem Pflanzenöl als Biotreibstoff in Traktoren und zur Nutzung des Ölkuchens von Leindotter in der Nutztierfütterung beschrieben und deren Bedeutung für die Treibhausgas(THG)bilanz landwirtschaftlicher Betriebe dargestellt. Bei Einführung von Mischfruchtanbausystemen mit Ölpflanzen und der konsequenten Nutzung aller erzeugten Komponenten im Betrieb können THG-Emissionsminderungen in der landwirtschaftlichen Produktion, durch die Ertragsstabilisierung durch den Mischfruchtanbau sowie durch die direkte Substitution von Dieselkraftstoff in landwirtschaftlichen Fahrzeugen und von sonst importierten Futterkomponenten für die Nutztiere erzielt werden.

Schlüsselworte: Ökologischer Landbau, Futterkomponenten, Nahrung und Biokraftstoff, Mischfruchtanbau

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1. Introduction

Mixed cropping is a management tool that is used in organic farming in terms of efficient resource use and risk minimization (Jensen, 2006; Hof and Rauber, 2003). A very special production line is mixed cropping with oil crops (Paulsen, 2007a and 2008a; Carr et al., 2003; Szumigalski and van Acker, 2005 and 2006). Due to very insecure yields of oil crops in organic farms mixed cropping could be used to secure oilseed production at all if suitable companion crops are found. Special yield goals of this cropping type could be defined for co-production of food and renewable energy.

As straight vegetable oil can be directly used as fuel for farm machinery (Ramadhas, 2004; Hassel and Wichmann, 2005) oil crop yield from mixed cropping must be adapted to the fuel demand of the farm and feed crops could be produced parallel (Paulsen, 2008b; Paulsen and Rahmann, 2004).

GHG loads of organically produced vegetable oil can be very low due to the low external energy input in organic production (Cormack, 2000). Oil crops cultivated in mixed cropping systems have additional energy demands for technical equipment for seeding and separating the seeds after harvest. Furthermore probable yield reduction of the main crop would cause loads for the oil crop e. g. in GHG balances. But also positive yield effects of companion oil crops are reported. This would have reducing effects on the GHG emission of whole production as well as the use of renewable energy. Additionally oil cake from oil production can replace other imported feed components with indifferent climate loads (Steinfeld, 2006).

Mixed cropping for energy production would probably be needed in various elements of a crop rotation to supply sufficient fuel in organic farming. This implies a need for the use of vegetable oil from different oil crops in the machines and for the use of different oil-cakes in animal feeding.

In the following recent own research results on yield of mixed cropping systems with different oil crops in organic production, results on the use of camelina oil as fuel component in agricultural machinery and on oil cake in chicken feeding are summarized. Based on these results the effects of the introduction of these measures on the green house gas (GHG) load of production are discussed.

2. Materials and Methods

Field trials

Field trials of mixed cropping with oil crops were undertaken at four sites in Germany with the oil crops camelina (false flax, *Camelina sativa L.*), linseed (*Linum ustitatissivum L.*), rape (*Brassica napus L.*), safflower (*Carthamus tinctorius L.*) and white mustard (*Sinapis alba L.*). The oil crops were sown in completely randomized block designs with four repetitions together with different legumes (pea - *Pisum sativum L.* or blue lupin - *Lupinus angustifolius L.*) or cereals (wheat - *Triticum aestivum L.*, barley - *Hordeum vulgare L.* or rye - *Serale cereale L.*). In mixtures with winter rape winter varieties were used as cropping companions (Table 1). Also the mixed cropping of two oil crops – linseed together with camelina – was tested. In the following text the introduced oil crops are further called ‘oil crops’. The other crops in the mixture are called ‘main crops’. Both crops were sown in separate rows and optimal depths each. The seed row distances were kept constant in sole and mixed cropping (12 to 12.5 cm). Consequently most seed rates of oil crops and main crops were reduced to 75 % or 50 % compared to the sole cropping, according to existing field experiences. The trial design is given in Paulsen (2007b). Yield effects compared to sole cropping therefore could be expected by plant reduction per area, by different intrarow plant distances as well as by interrow plant competition of different varieties. After harvest the seeds were divided and weighed separately. Additionally all crops were grown in pure stand to calculate the Land Equivalent Ratio (LER) (Mead and Willey, 1980).

Feeding trials with oil cakes

Camelina oil cake was taken as example for a novel crop with special fatty acid composition and its usability in diets for broiler fattening. Camelina oil cake as ingredient was critically discussed in terms of negative influences on fat odour and taste when used in pig or broiler nutrition (Böhme and Flachowsky, 2005). Since 2008 it is accepted in the EU feed law (Commission directive 2008/76/EC). In a feeding trial on chicken fattening energy equal feed rations with 0, 2.5 or 5 % camelina oil cake were used. Chicken were slaughtered, parameters of fattening performance, carcass quality, organ weights and sensoric meat quality were determined (Weissmann et al., 2007).

Tests in straight vegetable oil driven tractors

Usability of mixed straight vegetable oils as fuels was exemplarily examined in agricultural tractors with engines adapted to the use of straight rape oil. Two modern common rail tractors with 150 kW were compared over 1000 h in one year in a field test. One tractor was driven with cold pressed rape oil and one with a mixture of 30 % camelina oil and 70 % rape oil. Fuel qualities were examined according to DIN V 51605 (2006). Motor oil samples were controlled on vegetable oil content, viscosity and carbon residues.

Estimation of GHG loads

The potential of GHG reduction on farms by the substitution of diesel fuel by straight vegetable oil was calculated with an emission factor of 83.3 g CO_2eq/MJ diesel and an energy content of diesel of 43 MJ/kg or 36 MJ/l (EU, 2009).

3. Results and Conclusions

Yield potential of mixed cropping with oil crops

Mixed cropping is seen as measure to ease overall yields, due to different growing habits and resource demand of the different plants (Trentbarth, 1986). Due to this and to special site conditions also in the reported trials a very large bandwidth of yield combinations was obtained. Reasons for the yield variation were low field establishment of spring seeds due to spring drought periods (obvious in low yield levels of the main crop in sole cropping), problems with seeding technology of fine seeds and insect pests (*Melingetes anuus*) on nearly all sites and years in all cruciferous plants which is typical for organic farming conditions (Petterson et al., 2002; Valantin-Morison and Meynard, 2007 and 2008). In Table 1 the average yields over all sites and years are given. The results are given in detail by Paulsen and Schochow (2007).

Table 1:

Average grain yields of mixed and sole cropping systems of various main crops and oil crops in organic farms [kg/ha dry matter] and land equivalent ratio of mixed cropping (LER) (4 German sites in 2004 and 2005)

	oil crops		main crops		mixed cropping	LER
crop combination	sole	mixed	sole	mixed	total	
winter varieties:						
barley/rape	720	250	3580 a	1910	2160 b	0.88
rye/rape	610	230	4490 a	2630	2750^{b}	0.96
pea/rape	720	490	320 b	370	870 a	1.84
spring varieties:						
pea/camelina	1100	750	1470 b	1120	1870 a	1.44
pea/camelina[l]	1260	470	2480 b	2350	2830 a	1.32
pea/rape	40	40	1470 b	1760	1800 a	2.20
pea/w. mustard	630	450	1470 a	700	1150 b	1.19
lupin/camelina	1100	750	1410 b	910	1660 a	1.33
lupin/safflower	1080	800	1410 a	470	1270 a	1.07
wheat/camelina	1100	370	3660 a	2660	3030 b	1.06
wheat/linseed	740	140	3660 a	2990	3140 b	1.01
camelina[m]/linseed	740	240	1100 a	890	1140 a	1.13

[l] camelina in broadcast seeding, [m] main crop camelina
a,b: significant differences between yields of main crops are indicated by different letters ($p < 0.05$)

Mixed cropping of legumes with rape or camelina on average lead to a remarkable total yield increase compared to the sole cropped main crop. High LER values between 1.32 and 2.20 indicate the high area efficiency of production of those mixtures (Table 1).

Camelina delivered on average between 370 and 750 kg/ha seeds with a moderate yield reduction of the main crops (pea or blue lupin). LER values between 1.32 and 1.44 were reached. Maximum yields of 1.75 t and 2.36 t ha camelina occurred in pea or *L. angustifolius*, respectively. At this yield level the yields of the main crops were strictly reduced (Paulsen, 2007a). Pea (winter variety) was kept upright by the rape (winter variety) and reached higher yield in mixed cropping. But both cultures were at an unsatisfactory low yield level. Flowers and seeds of rape (spring variety) were almost destroyed completely by insects in mixed and sole cropping. This and an average yield increase of pea in mixed cropping with rape (spring variety) lead to the high LER value of 2.2. Due to their described extreme yield risk mixtures with rape need further evaluation.

Safflower proofed to be very competitive in mixture with *L. angustifiolius*. At an LER of 1.07 of mixed cropping the yield was dominated by safflower (Table 1). This tendency was additionally increased by the differing ripening times of both cultures which lead to pre-harvest yield losses in blue lupin. Further camelina or linseed were dominated by spring wheat in mixed cropping. Spring wheat realized disproportionately high yields in mixed cropping if plant number reduction and extension in row distances in relation to sole cropping which were given by the trial design are considered. In those systems the oil crops camelina or linseed showed seed yields of 370 kg/ha and 140 kg/ha (dry matter), respectively. Maximum yields of camelina of 960 kg/ha (dry matter) only occurred together with low yield levels of the main crop spring wheat (Paulsen, 2007b). In mixed cropping with linseed, camelina dominated the yield. But also in the four latter mixed cropping systems LER values larger than one could be reached (Table 1). Except the mixtures pea/white mustard and lupin/safflower in all mixed crops the main crops had relative yields higher as 0.5. This means that yield increases in food production are possible parallel to the production of renewable fuel.

Mean absolute yield gains and losses of mixed cropping with oil crops in organic farms at same area use both cultures would have in sole cropping are tabulated in Table 2. This scenario can be helpful, when oilseeds shall be produced in the farm and mixed cropping shall help to overcome cropping difficulties e. g. in weed or pest management (Saucke and Ackermann, 2006; Paulsen et al., 2006; Paulsen et al., 2007b). Therefore in Table 2 the introduction of 2 ha mixed cropping is compared with the production of 1 ha of each culture in sole cropping.

Except for combinations of pea with white mustard and of blue lupin with safflower all combinations lead to an improvement of the absolute seed production of the main crop on farm level. Oil crops were produced in all systems. A decrease in oil crop production on farm level compared to sole cropping systems was obvious in combinations of oil crops with wheat, when camelina was grown in broadcast seeding together with peas, in most combinations with rape and finally in linseed if combined with camelina (Table 2).

Table 2:

Yields and yield gains or losses by mixed cropping compared to sole cropping at equal land use [kg/ha dry matter]

	farm yield 2 ha				additional	
	mixed cropping		sole cropping		farm yield by mixed cropping	
	/ 2 ha		/1 ha	/1 ha	/1 ha	
crop combination	oil crop	main crop	oil crop	main crop	oil crop	main crop
winter varieties:						
barley/rape	500	3820	720	3580	-110	+120
rye/rape	460	5260	610	4490	-75	+385
pea/rape	980	740	720	320	+130	+210
spring varieties:						
pea/camelina	1500	2240	1100	1470	+200	+385
pea/camelina[l]	940	4700	1260	2480	-160	+1110
pea/rape	80	3520	40	1470	+20	+1025
pea/w. mustard	900	1400	630	1470	+135	-35
lupin/camelina	1500	1820	1100	1410	+200	+205
lupin/safflower	1600	940	1080	1410	+260	-235
wheat/camelina	740	5320	1100	3660	-180	+830
wheat/linseed	280	5980	740	3660	-230	+1160
camelina[m]/linseed	480	1780	740	1100	-130	+340

[l] camelina in broadcast seeding, [m] main crop camelina

But an overall yield gain (oil crops + main crops) in all mixed cropping systems is obvious. The decision which cropping system is preferred therefore is dependant of yield risk assessments of sole cropping and of positive aspects mixed cropping may deliver (physical stabilisation aspects, weed suppression, yield buffering aspects). Also goals for seed yields will influence the choice of the cropping system.

Organic mixed cropping systems with camelina proofed to be relatively robust in yields and ripening times over the years and showed yield buffering capacities. Therefore further studies on the use of its oil and oil cake on farms were undertaken. These experiences are described in the following. The possible effects on changes of GHG balances on farm level after introduction of the system are estimated.

Use of oil cakes in livestock feeding and alternative usages

In organic livestock nutrition the use and production of a sufficient amount of high-quality feed components containing protein and amino acids is essential for the creation of pure on farm diets (Zollitsch et al., 2004). The use of locally produced oil cakes would help to avoid external environmental effects and GHG loads by import of feed components (Steinfeld et al., 2006). Replacement of oilcake from soya (*Glycine max)* which might be polluted with GMO from conventional production (Partridge and Murphy, 2004) would be another important aspect to guarantee food security in organic farms.

In terms of its gucosinolate contents and its content of linolen- and linolenic acid the use of camelina oil cake in animal nutrition was critically discussed (Böhme and Flachowsky, 2005). Further trials on an adequate dosage in poultry production were undertaken (Jaskiewicz and Matyka, 2003; Weissmann et al., 2007). Today there is a general allowance of the ingredient in livestock feeding (Commission directive 2008/76/EC).

Table 3:

Effects of the complete replacement of oil cake of soya (5 %-content) by oilcake of camelina in feeding ratios for chickens on performance and meat quality (Weissmann et al., 2007)

	G. max oil cake	Camelina oil cake
Fattening performance, n=	44	48
Slaughtering weight, g	3741 b	3883 ab
Daily weight gain, g	44.0 a	45.8 a
Feed intake, g/d	100.7 bc	107.6 ab
Feed conversion, g/g	2.38	2.35
Organ weights, n=12		
Thyroid, g	0.341 b	0.351 b
Liver, g	70.8 ab	74.3 ab
Carcass yield, %	69.4 ab	69.5 ab
Sensoric meat quality (leg) (1= bad, 6=very good)		
Tenderness	4.3	4.2
Juiciness	4.3	4.5
Aroma	4.1	3.9
Fatty acid composition of intramuscular fat		
SFA[1], %	28.2 a	28.0 a
MUFA[2], %	38.5	40.5
PUFA[3], %	33.1	31.3
Rest, %	0.2	0.2

a, b, c: different letters indicate significant differences ($p \leq 0,05$),
[1] Saturated Fatty Acids: C14:0 , C16:0, C18:0; [2] Mono Unsaturated Fatty Acids: C16:1, C18:1, C20:1, C22:1; [3] Poly Unsaturated Fatty Acids: C18:2, C18:3, C20:4

Results on the successful complete replacement of soya oil cake by camelina oil cake in organic chicken feed ratios are presented in Table 3, exemplarily. Animal performance and meat quality in the chicken fattening were not influenced (Weissmann et al., 2007).

The consequences for the reduction of GHG of organic production which might be caused by this replacement is unclear but would surely be high if land use changes for e. g. organic production of soya can be avoided (Weightman et al., 2010).

Alternative usages of the oil cakes are seen in organic fertilisation (Laber, 2003) and in the use as additional substrate in biogas plants (Paulsen et al., 2009). In general usages like this might cause additional mitigation effects on GHG emissions of farms by substitution of other fertilisers, by a yield increase through fertilisation or by the substitution of other biogas co-substrates and the increase of the amount of renewable energy that is produced.

Tests in straight vegetable oil driven tractors

Tractors which were technically adapted to the use of straight vegetable oil as pure fuel are on the market or can be constructed by special suppliers. Several studies on the use of vegetable oil in diesel engines are available (Ramadhas, 2004; Knothe et al., 1991) and were updated in practical field studies with modern agricultural machinery that was adapted to the use of rape oil according to the DIN V 51605 in Germany (Hassel and Wichmann, 2005) and Austria. Research on possibilities to fulfill the coming exhaust regulations and on the newest technical development is running in an EU-wide demonstration project (http://www.2nvegoil.eu/default.asp?Menue=93). Further technical development concentrates on the purification of cold pressed and refined vegetable oils to exclude unwanted P, Ca, Mg contents (Remmele, 2002; http://www.faqs.org/patents/app/20100024284).

For the demands of organic farming and of the mixed cropping approach a variety of oil crops is needed to be used in engines. The results of the exemplary field tests on the replacement of 30 % rape oil by camelina oil and the use as mixed fuel can be summarized as follows:

The tractor was driven without complications over 1000 h under different loads. The motor oil quality was always suitable and wide below critical thresholds (vegetable oil content, carbon particles, viscosity) also after the maximum period between the oil change of 350 h that was used.

Oxidation resistance of the straight vegetable fuel mixture was always under the DIN norm given for rape oil when used as fuel (Table 4).

Table 4:

Parameters of fuel characteristics of a 70 %/30 % mixture of rape oil and camelina oil

Parameter	Unit	Threshold DIN V 51605**	Oil mixture
CCR*	%(m/m)	≤ 0.40	0.46
Iodine number	g/100g	95 - 125	125
Acid value	mg KOH/g	≤ 2.0	1.59
Oxidation stability	h	≥ 6.0	4.0
P-content	mg/kg	≤ 12	11
S-content	mg/kg	≤ 10	3
Σ Ca + Mg	mg/kg	≤ 20	20.9

* Conradson Carbon Residue, **parameter CCR not any longer listed in the final DIN 5160 and new thresholds for P: 3 mg/kg, Ca: 1 mg/kg, Mg: 1 mg/kg valid in 2012

After 1000 h carbonaceous deposits at the fuel injectors were detected. But it remained unclear if they were caused by the use of cold pressed oils which in general are of lower pureness than raffinates or by the use of the oil mixture itself because Ca and Mg contents of straight camelina oil was nearly in range with that of the rape oil that was used. Anyway the CCR values of the oil-mixture exceeded the threshold given in the DIN V 51505 (Table 4). The tractor had the same power and showed no difference in emission of NO_x, CO, HC and particles compared to the use of straight rape oil. Principally the use of 30 %/70 % camelina/rape oil as fuel in diesel engines that are adapted to the use of straight vegetable oil is possible. In general increased attention on motor control (injectors, motor oil quality) must be taken when cold pressed and unrefined vegetable oil is used. But the use of vegetable oil beyond the DIN norm cannot be recommended if warranty aspects of the engines are considered.

But market studies on the practical trading of vegetable oils showed that different vegetable oils are mixed as fuel and are sold as vegetable oil according to DIN V 51605 (Paulsen et al., 2007a). Vegetable oil mixtures for the use as fuel are obviously market conform and can therefore be part of considerations on the replacement of fossil fuels.

Estimation of GHG loads

The additive potential of the mixed cropping system, the use of the vegetable oils as fuels in agricultural machinery and the use of oil cake as feed component to reduce the emission of CO_2-equivalents per hectare must be calculated based on the allocation of emission factors for the substituted materials (fossil fuel and other feed components) and by the hectare wise yield effects of the mixed cropping systems. Values on these overall effects of mixed cropping for the described mean yield levels (Table 1) are given in Table 5.

Table 5:

Gains (+) and losses (-) in grain yields (dry matter) of various main crops in organic farms (a), additional oil (b) and oil cake yields (c) and change in produced raw protein (XP) (d) and energy production (e) when mixed cropping with oil crops is introduced (yields: see Table 1 and 2) and the reduction of GHG emissions by the substitution of diesel fuel by the produced straight vegetable oil (f)

	(a)	(b)	(c)	(d)	(e)	(f)
crop combination*	+/-	+	+	+/-	+/-	-
	main crops	veg. oil	oil-cake	XP ^{b}	heating value	CO_{2eq}
	kg/ha				^{c}MWh/ha	^{d}kg/ha
winter varieties:						
barley/rape	-1670	100	150	-105	-6.3	-313
rye/rape	-1860	92	138	-95	-7.3	-288
pea/rape	+50	196	294	+126	+3.7	-614
spring varieties:						
pea/camelina	-350	285	465	+116	+3.6	-893
pea/camelina^{l}	-130	179	291	+118	+2.7	-561
pea/rape	+290	16	24	+6	+1.7	-50
pea/w. mustard	-770	113	338	-26	-0.5	-354
lupin/camelina	-500	285	465	+11	+2.9	-893
lupin/safflower	-940	160	640	-229	+1.1	-502
wheat/camelina	-1000	141	229	-16	-2.2	-442
wheat/linseed	-670	53	87	-55	-2.2	-166
camelina^{m}/linseed	-210	91	149	+17	+0.7	-285

^{l} camelina in broadcast seeding, ^{m}main crop camelina, ^{b}effects of mixed cropping on grain N contents are considered, XP=N*6.25, ^{c}oil crops 7 kWh/kg dry matter, cereals/legumes 4.8 kWh/kg dry matter, ^{d}3603.4 gCO_{2eq}/kg diesel = 83.8 gCO_2eq/MJ (EU 2009)

On the contrary to the interpretation given in connection with Table 2 the values in Table 5 have to be interpreted with the background that mixed cropping is introduced in a farm to combine feed and fuel production in one field. So the pure yield effect per hectare is given here and not the effect on farm level.

Under this assumptions in the most cropping systems the kernel yield of the main crop per hectare is reduced, exceptional are pea (winter variety) yields in combination with rape (winter variety) and pea in combination with rape (spring variety) (Table 5, column a). This was also found in other studies on combinations of rape with cereals (Szumigalski and van Acker, 2005), wheat and linseed (Carr et a., 1993), safflower in combination with seed legumes, rape or turnip rape *(Brassica campestris L.)* (Rafey and Prasad, 1991) and beans *(Vicia faba L.)* in combination with safflower or linseed (Kiessling, 2011). But also yield increases respectively yield constancy of peas in mixed cropping with false flax compared to sole cropped peas can occur (Saucke and Ackermann, 2006). But inherent to the system all mixed cropping systems delivered additional vegetable oil and oil cake per hectare (Table 5, columns b and c). Considering the total produced raw protein of the different crop combinations (Table 5, column d) it is obvious that if the yield reductions are moderate and the oil yields are relatively high additional protein can be produced. This protein can replace necessary feed protein imports and replace their GHG loads directly or can increase the yield of livestock production by high quality farm own feed components. This can decrease the product related GHG emissions.

The heating value of the whole seed production of mixed cropping compared to the sole cropped main crops is given as integrating value for overall energy production of the systems (Table 5, column e). The combinations delivering higher protein yields and also the combination of blue lupin with safflower show an energy win per hectare compared to the sole cropping of main crops. In the latter combination high yield losses in blue lupin occurred and the raw protein losses on this side couldn't be compensated by safflower, whereas the energetic approach delivered an increase in energy per hectare due to the assumed heating value of the oil crop.

By the direct replacement of fossil fuel with vegetable oil from mixed cropping between 50 and 893 kg/ha CO_2-equivalents could be replaced (Table 5, column f). Assuming a fuel demand for agricultural machinery of 100 kg/ha farmland average straight vegetable oil yields from 1 ha could make up to 3 ha self reliant in fuel. With the maximum values of oil production in mixed cropping with camelina reported before fuel self-reliance for up to 9 hectare could be reached with 1 ha farmland.

Further considerations of the effects of mixed cropping systems with oil crops have to consider the possible additional energy demand for their introduction. It can be minimized e. g. by the combination of seeding technology (Paulsen und Pscheidl, 2007). Additional factor demands of mixed cropping arise in the seed production and in the seed separation after harvest. But these points are seen to be of minor importance in life cycle balances (Sergis-Christian und Browers, 2005) and must be compensated by the advantages of the cropping systems described before. In general mixed cropping with oil crops in organic farming is seen as highly specialised opportunity to produce oil crops (Gruber and Vogt-Kaute, 2007) which has clearly to be adapted to site conditions.

Conclusions

Mixed cropping with oil crops can enable organic farmers to introduce oil crops in their crop rotation. Looking from this direction mixed cropping on one field compared to sole cropping of main and oil crops on different fields lead to increased farm production of both products. This alone can mean clear reducing effects on the product related GHG emission of organic agricultural production.

Mixed cropping with oil crops can also be introduced as cropping concept to produce straight vegetable oil as fuel for agricultural machinery. Yields of the main crops will be reduced in that case but are replaced by products with other quantities and qualities. This has to be considered in farm balances and in their scenario descriptions.

With straight vegetable oil from mixed cropping with oil crops fossil fuel can be replaced. The co-product oil cake and an increased protein production per hectare mean an added value for livestock productivity and a reduction of imported feed components can be expected. These aspects offer clear potential of the described system to reduce GHG emissions of organic farms. The production of biofuel in this way has only moderate competition to food production.

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