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N-REQUIREMENT OF MIXED-CROPPING SYSTEMS WITH OIL CROPS IN ORGANIC FARMING

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Introduction

Mixed cropping systems with oil crops are of growing interest in organic farming systems. They can offer agricultural advances like competition against weeds, support against lodging and buffering of yield fluctuations. The aim of the cultivation method is to gain additional oil yields for energy or feed purposes (PAULSEN and RAHMANN 2004). The reported higher land-efficiency-ratios of those mixed cropping systems should lead to higher nutrient requirements per area. But it is unknown whether the different crops just compete for rare soil nutrients or if complementary effects in mixed cropping systems lead to higher nutrient efficiency (HØGH-JENSEN and SCHJOERRING 2000). Different root systems and different developing times could support the nutrient uptake or increase the usage of plant nutrients from the soil (VAN RUIJVEN and BERENDSE 2005, FUJITA et al. 1992). In a field study N-contents in plants of diverse mixed cropping systems during stem elongation and the total nutrient uptake at harvest are compared to corresponding sole cropping systems.

Materials and Methods

The field trials were designed as randomised block design with four replicates and conducted at two organically managed sites in northern Germany in 2003 and 2004. Climate and soil conditions are described in Table 1. The preceding crop was clover grass at all sites.
The following mixed cropping systems were analysed: Wheat (*Triticum aestivum L.* 'Fasan') x linseed (*Linum usitatissimum L.* 'Gold Merchant'), wheat x false flax (*Camelina sativa L. Crantz,*

'Pernice'), pea (*Pisum sativum L.* 'Madonna') x false flax, pea x white mustard (*Sinapis alba L.* 'Albatros'), blue lupin (*Lupinus angustifolius L.* 'Boruta') x safflower (*Carthamus tinctorius L.* 'Sabina'). For the comparison of the N-supply and N-uptake of the plants, each plot sown with the mixed cropping systems had two corresponding plots sown with the sole crops.

Table 1: Climate and soil parameters at the experimental sites in North Germany, 2004

		Trenthorst			Wilmersdorf		
		1971-2001	**2003**	**2004**	**1971-2001**	**2003**	**2004**
Climate							
Average Temperature	**°C**	**8.7**	8.9	8.3	**8.5**	8.9	7.9
Rainfall	**mm a^{-1}**	**735**	492	727	**528**	416	495
Soil							
Clay	**%**		18	14		9	9
			sandy loam	sandy loam		loamy sand	loamy sand
Soil organic matter	**%**		1.9	2.1			1.8
Root zone	**m**		1.2	1.2		1.0	1.0
pH			6.9	6.4			6.1
Available P	**mg kg^{-1}**		1.1	0.9			0.5
Available K	**mg kg^{-1}**		1.8	1.3			1.2
Available Mg	**mg kg^{-1}**		0.8	1.2			1.3
Soil N_{min} (spring, 0-60 cm)	**kg ha^{-1}**		37	45		57	40

Suitable seed densities were chosen according to the local knowledge on those mixtures and the sole crops. The relative seed density of the mixture components in relation to the sole crops varied between 50 and 100 percent (Table 2).

Table 2: Seed densities in the mixed and sole cropping experiment with oil crops

	Mixed crops Seeds m^{-2}	**Sole crops** Seeds m^{-2}	**Mixture crops in percent of sole crops** %
Wheat x Linseed	200/400	400/600	50/66
Wheat x False Flax	200/360	400/360	50/100
Pea x False Flax	80/360	80/360	100/100
Pea x Mustard	60/40	80/80	75/50
Lupin x Safflower	75/75	100/100	75/75

Row distances were 6.75 cm and 12.5 cm in the mixed crops in the years 2003 and 2004 respectively. Sole crops were drilled with 12.5 cm row distance in both years.

Vegetative plant samples were taken at the beginning of shooting stage by harvesting the above ground biomass. Seed yields were determined with a plot-combine by central harvesting. Straw yields were determined only in 2004 by harvesting 1 m^2 by hand. All plant samples for 2004 and the vegetative samples taken in the shooting stage of 2003 were dried at 60° C and ground to 0.12 mm with a centrifugal mill. The N-contents of the plant samples were determined according to DUMAS with dynamic combustion with an Elementals Analyser EUROEA 3000 (KIRSTEN 1983). Data on N-contents and N-uptake of the plants were analysed by analysis of variance with Costat Statistical Software (SIMONS 1995).

Results and discussion

Mass yield and Relative Yield Total

Mixed cropping systems can be characterized by the relative yields total (RYT) which is sum of the relative yields of the single components of a mixed cropping system in relation to the sole crops (DE WIT 1960, DE WIT and VAN DEN BERG 1965). RYT-values >1 indicate higher efficiency in the use of growth resources (e. g., land use, water, nitrogen) of the mixed cropping system, values lower than one indicate its lower efficiency. Table 3 shows the RYT values of the mixtures in the trials of 2004. RYT values >1.2 are highlighted.

Table 3: Relative seed density of mixed cropping systems and RYT of the biomass yields, mean of two sites, 2004

Mixed crops	Relative seed density	RYT		
		Biomass	Seeds	Straw
Wheat x Linseed	1.16	0.96	0.91	1.00
Wheat x False Flax	1.50	1.08	**1.22**	1.04
Pea x False Flax	2.00	**1.31**	**1.33**	**1.32**
Pea x Mustard	1.25	0.98	0.79	1.04
Lupin x Safflower	1.50	**1.22**	1.09	**1.31**

Mixtures of *false flax* with *peas* or *wheat* had higher productivities (RYT) than the compared sole crops. This can be interpreted as higher resource utilisation efficiency (TRENBARTH 1986) of the mixed cropping system. The chosen mixed cropping system of *pea* and *false flax* had an additive design (seed density 100 % of each component, see: Tables 2 and 3). Yield increases of this combination can be seen as a real positive effect of the mixed cropping of the plant species. This might be an effect of the limited competition situation for N, because the legume component is mainly independent from the available soil N (AUFHAMMER 1999). False flax was high yielding in 2004 and could compensate for insufficient pea yields (Figures 1 and 2).

In replacement designs of mixed cropping, e. g., in the mixture of *wheat* and *false flax* (Table 3: relative seed density < 2) the interpretation of the reasons for the positive effects is seen at least as more difficult than in additive designs (SNAYDON 1991, CONOLLY 1986, JOLLIFFE et al. 1984) because single crop yields in the mixtures are compared to sole cropping yields with different seed densities. But experimental designs for agronomical questions of mixed cropping systems are commonly made with replacement mixtures to adopt the mixed crop to specific growth conditions and to production intensities (AUFHAMMER 1999). Even for this study replacement designs had to be chosen to examine mixed and sole cropping systems that are suitable for agricultural practice even if interpretation of competition effects is more insecure.

In 2004, the absolute seed and biomass yields of all single crops in the mixtures were clearly lower than in their corresponding sole cropping systems (Figures 1 and 2).

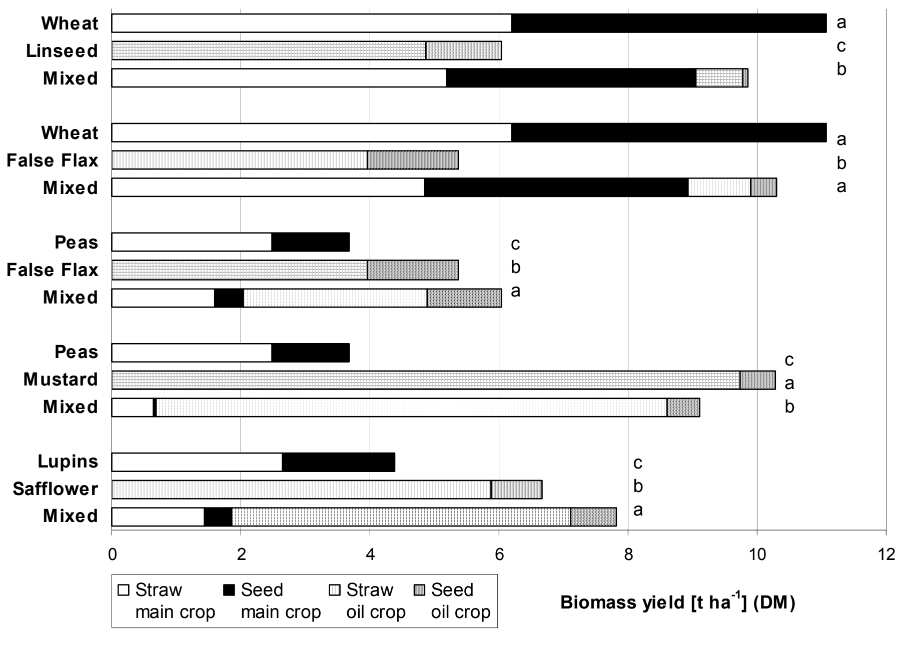

Figure 1: Seed, straw and biomass yields (seeds and straw) of mixed cropping systems with oil crops in comparison to the sole cropping yields, Trenthorst, Germany 2004

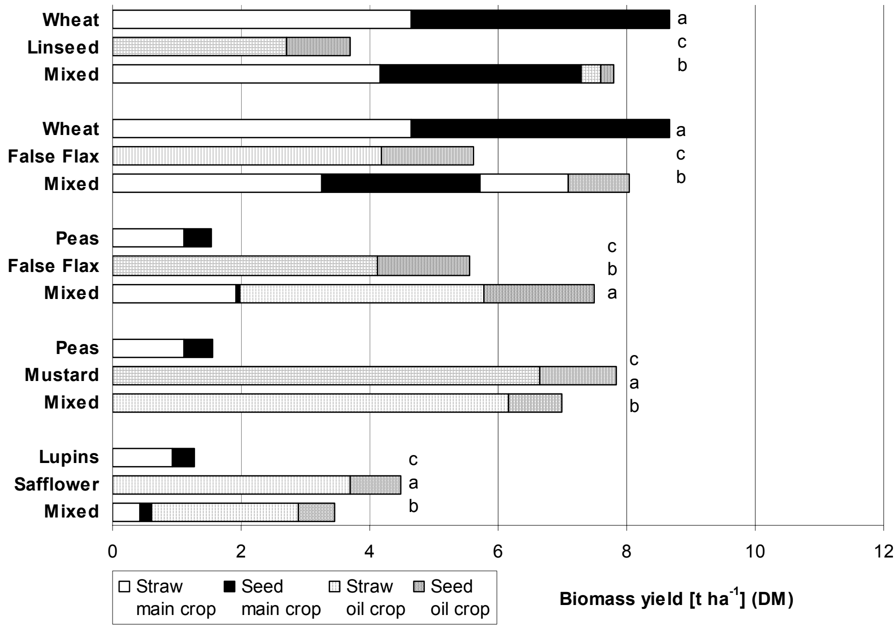

Figure 2: Seed yields and biomass (seed and straw) yields of mixed cropping systems with oil crops in comparison to the sole cropping yields, Wilmersdorf, Germany 2004

In the additive mixture of *pea* and *false flax,* the *false flax* dominated and reached higher yields than *peas* in sole and mixed cropping. In the replacement mixtures *safflower* with *lupins,* and *peas* with *mustard,* the oil crops dominated the legumes very clearly. In the intercropping systems of *wheat* with *false flax* or *linseed* the lower yield of the *wheat* might be interpreted as pure effect of the lower seed density of *wheat* compared to the sole cropping (50%, Table 2). This view is supported by the heavy yield decrease of the oil crops in the intercropping system indicating the dominating competitive strength of wheat. Nevertheless RYT values of the *spring wheat – false flax* mixture are > 1 (Table 2) and indicate higher resource use efficiency.

The high N-concentrations in the crops in Wilmersdorf in 2003 can be explained by the higher mineral N content in soil (Table 1). The *legumes* and *safflower* in the trials ranged in the normal nutrient content levels for those crops (Table 4).

N-supply in spring

Adopted standards for sufficient leaf nutrient contents to reach the yield level of organic farming are not developed. Only in fertilised systems are adequate limits of N-concentrations to reach a yield optimum known for different crops (BERGMANN 1992). Plant N-contents between 4 to 6 % are demanded for *spring wheat* in the shooting stage, and between 3 and 4 or 2.6 and 4 % for *peas* or *linseed* at beginning of flowering, respectively. N-contents of sole cropped *wheat* or *linseed* in the described trials under organic farming management normally did not reach those levels (Table 4). Since a lack of available nitrogen in Spring is typical for organic production, effects of N-competition should be enforced under organic conditions.

Table 4: N-content in the plant tissues at the beginning of the shooting stage (*wheat, safflower*) and the beginning of flowering (*lupins, peas, false flax, linseed*) in the sole cropping systems

Site / Crop	Spring wheat	False Flax	Linseed	Peas	Safflower	Lupins
Trenthorst 03	2.0	2.8	2.5	**4.1**	3.2	2.5
Wilmersdorf 03	**4.6**	5.8	**6.2**	-*	-*	-*
Trenthorst 04	2.4	2.5	2.2	**3.0**	2.7	2.8
Wilmersdorf 04	1.9	1.8	2.3	2.8	2.0	3.1
Optimal N content	**4-6**[1)]	**1.8-2.8**[2)]	**2.6-4**[1)]	**3-4**[1)]	**2.6-3**[3)]	[4)]

*no sample in 2003, [1)]Bergmann 1992, [2)]this study: leaf contents for a yield of >1,4 t ha^{-1} (figures 2 + 3)
[3)]Heikal 1977 [4)]not known

For *false flax,* values for a sufficient N-supply in spring are not reported in literature. In the described trials, *false flax* reached seed levels of over 1.4 t ha^{-1}, which is a high yield level for unfertilised systems (HORNERMEIER and AGEGNEHU 1994). In those plots, plant N-contents were between 1.8-2.8 % at shooting stage, and can therefore be seen as a sufficient level for that culture.

The comparison of N-contents in the tissue of the single crops at the shooting stage in mixed and pure stands showed elevated N-concentrations in *false flax* and in *peas* when intercropped with each other. Obviously the two cultures do not compete for N in this growing stage. But a transfer of rhizobial nitrogen (HØGH-JENSEN AND SCHJOERRING 2000, HAUGGAARD-NIELSEN and JENSEN 2005) from *peas* to *false flax* could not be proven by the data. In the mixtures of *safflower* and *lupins* no effects on the N-content were measurable at this growth stage (Table 5). At harvest seed and biomass yields of both mixtures where dominated by the oil crops (Figures 1 and 2).

Table 5: Nitrogen content (DM %) of plants in the shooting stage in mixed and sole cropping systems with *Peas* and *False Flax* or *Blue Lupins* with *Safflower*, Trenthorst, mean of two years, 2003 and 2004

	Peas (False Flax[1)])	**False Flax** (Peas[1)])	**Safflower** (Lupins[1)])	**Lupins** (Safflower [1)])
Mean sole crop	3.5	2.7	2.9	2.7
Mean mixed crop	3.7	3.2	2.7	2.6
F-Test cropping system	*	***	**ns**	**ns**
$LSD_{5\%}$	**0.16**	**0.25**	**-**	**-**

[1)] Component crop   * *p<0.05*   ** *p<0.01*   *** *p<0.001*   ns= not significant

In cropping systems with *spring wheat* mixed with *false flax* or *linseed* the *wheat* is dominating the mixtures until harvest (Figures 1 and 2). N-concentration in vegetative tissue at the beginning of the shooting stage of *wheat* was not influenced by the cropping system whereas the component oil crops showed lower N concentrations compared to plants from sole cropping (Table 6). Obviously the oil crops already suffer real N competition in those systems.

Table 6: Nitrogen content (DM %) of plants in the shooting stage in mixed and sole cropping systems with *False flax* or *Linseed* as component crop in *Spring Wheat*, mean of two sites and two years, Trenthorst and Wilmersdorf, 2003 and 2004

	False Flax (Wheat[1)])	**Wheat** (False Flax[1)])	**Linseed** (Wheat[1)])	**Wheat** (Linseed [1)])
Mean sole crop	3.24	2.72	3.28	2.72
Mean mixed crop	2.60	2.55	2.57	2.85
F-Test cropping system	***	**ns**	***	**ns**
$LSD_{5\%}$	**0.25**	**-**	**0.21**	**-**

[1)] Component crop   * *p<0.05*   ** *p<0.01*   *** *p<0.001*   ns= not significant

N-supply and N-uptake at harvest

The N-contents of the plants at harvest do not reflect the trends found in Spring (Table 7). N-contents of seeds and straw were unaffected by the cropping system.

The average N-uptake of the different mixed cropping systems were 110, 132, 108, 102 and 65 kg ha^{-1} N for *spring wheat/linseed, spring wheat/false flax, pea/false flax, pea/mustard* and *lupin/safflower*, respectively. Whereas uptake of the sole crops was 128, 52 and 70 kg ha^{-1} N for *spring wheat, peas* and *lupins* and 64, 90, 115 and 47 kg ha^{-1} N for the sole cropped oilseeds *linseed*, *false flax*, *mustard* and *safflower* respectively. N-uptake of mixed cropping systems of *peas* in mixture with *false flax* or *white mustard* was significantly higher ($p<0.001$) than in sole cropped peas, which is the effect of the additional non-legumes in the mixtures (figures 1 and 2). The lower N-uptake of *spring wheat* in mixture with *linseed* compared to sole cropping ($p<0.05$) can not be purely explained by the mixture design because lower biomass yields of *spring wheat* (figures 1 and 2) might be determined by replacement design of the crop mixture with clearly reduced seed densities (table 2).

Table 7: Nitrogen content (DM %) of seeds and straw from plants in mixed and sole cropping systems with *Linseed* or *False Flax* as component crop in *Spring Wheat* and with F*alse Flax*, W*hite Mustard* or S*afflower* as component crop in *peas* or *lupins*, mean of sites Trenthorst and Wilmersdorf, 2004

Analysed crop (Component crop)	**Spring wheat** (Linseed)	**Linseed** (Spring wheat)	**Spring Wheat** (False Flax)	**False flax** (Spring wheat)
	Seeds / Straw			
Mean sole cropping	**2.2 / 0.6**	**3.7 / 0.6**	**2.2 / 0.6**	**4.4 / 0.7**
Mean mixed cropping	**2.2 / 0.5**	**3.7 / 0.7**	**2.3 / 0.5**	**4.5 / 0.7**
F-Test	ns / ns	ns / ns	ns / ns	ns / ns

Analysed crop (Component crop)	**Peas** (False Flax)	**False Flax** (Peas)	**Peas** (Mustard)	**Mustard** (Peas)	**Lupins** (Safflower)	**Safflower** (Lupins)
	Seeds / Straw					
Mean sole cropping	**3.6 / 1.3**	**4.4 / 0.7**	**3.6 / 1.3**	**5.7 / 0.8**	**5.3 / 0.7**	**1.9 / 0.7**
Mean mixed cropping	**3.4 / 1.2**	**4.5 / 0.7**	**3.5 / 1.7**	**5.6 / 0.8**	**5.4 / 0.8**	**2.0 / 0.7**
F-Test	ns / ns	ns / ns	ns / ns	ns / ns	ns / ns	ns / ns

N-efficiency

To find out if the assayed crop mixtures led to a more efficient use of available N, N-efficiency values were calculated. N-efficiency can be measured by the relation of biomass production to N-uptake (MOLL et al. 1982, SCHMIDKE and RAUBER 2000, VAN RUIJVEN and BERENDSE 2005).
For this study, values for relative N-Use-Efficiencies (RNUE) of the sole cropping in relation to the mixed cropping variants were calculated for seeds, straw and biomass yields according to the RYT definition from DE WIT (1960).

The following term was used:

$$RNUE = \text{N-efficiency}_{\text{(sole cropping)}} / \text{N-efficiency}_{\text{(mixed cropping)}}$$

with:

$$\text{N-efficiency} = \text{Yield}_{\text{(seed, straw or biomass)}} / \text{N-uptake}_{\text{(seed, straw or biomass)}} .$$

Table 8 gives the RNUE of the calculation. Values >1 indicate a higher N-efficiency of the plant species in the mixed cropping in comparison to the sole cropping system.

Table 8: Relative N-use-efficiency (RNUE) of plants in mixed cropping systems of cereals or legumes with different oil crops (Trenthorst and Wilmersdorf, 2004)

Mixed crops	Component crop	RNUE of mixed cropping					
		Biomass		Seeds		Straw	
		TRT	Wilm	TRT	Wilm	TRT	Wilm
Wheat x Linseed	Wheat	1.03	1.06	0.94	1.00	1.28	1.07
	Linseed	1.12	0.83	0.98	1.05	0.74	0.93
Wheat x False Flax	Wheat	0.97	1.07	0.96	0.95	1.10	1.28
	False Flax	0.86	0.78	0.94	1.02	0.92	1.14
Pea x False Flax	Pea	1.11	1.09	1.04	1.06	0.92	1.12
	False Flax	0.97	0.83	0.94	1.01	1.32	0.75
Pea x Mustard	Pea	1.26	0.69	1.07	0.95	0.81	0.75
	Mustard	0.94	1.10	1.03	1.03	0.94	0.94
Lupin x Safflower	Lupin	1.40	0.86	0.96	1.01	0.97	0.67
	Safflower	0.90	0.96	0.93	0.99	0.89	0.99

According to these data *peas* in mixture with *false flax* could produce higher amounts of biomass and even seeds per kg N-uptake (RNUE >1). That can indicate lower N-uptake of the *peas* from the soil or lower N-fixation caused by light competition (FUJITA et al. 1992) from the component oil crop that was dominating the biomass (Figures 1 and 2). The elevated N-efficiencies of *wheat* straw in mixture with *linseed* or *false flax* on both sites and of *false flax* in combination with *peas* in Trenthorst could be an effect of stimulated length growth of the plants by light competition in the mixtures. If this finding could be supported by length determination of the wheat stems, this effect could be of interest to break *Fusarium* spp. infection paths by creating longer distances from flag leaf to ear (LIENEMANN 2002).

All other N-efficiency values showed no systematic influences caused by the cropping system. Obviously N-efficiency is determined by site specific crop development. The reported high relative N-efficiency values for biomass for *linseed* in *wheat*, *peas* in *false flax*, *peas* in *mustard* and *lupins* in *safflower* look surprising but are reasoned in the addition of highly different values for mass yields and N uptake of straw and seeds before division.

Conclusions

Mixed cropping of *spring wheat* or *peas* with *false flax* led to RYT values >1 for the seed yield, indicating higher resource use efficiency. In mixed cropping of *lupins* and *safflowers* this was found for the straw yields.

In early growth stages *spring wheat* already competes efficiently for growing factors in mixture with oil crops. This is obvious in lowered N-contents in the component crops (*linseed* and *false flax*). Effects on seed and straw N-contents were not found in that year. *Spring wheat* dominates the mixtures until maturity. *False flax* and *linseed* yields are strongly decreased in mixed cropping with *spring wheat* compared to their sole cropping yields. Straw yields of *wheat* in those mixed cropping systems are gained with higher N-efficiency. In non-leguminous mixtures with RYT >1 (*spring wheat x false flax*), N-requirement exceeds the N-requirement of the sole crops.

In mixed cropping of *peas* and *false flax*, the N-content of vegetative tissue in early growth stages of both crops was supported. At harvest the effects were not measurable. Mixed cropping systems of *peas* with *false flax* or *mustard* consequently showed additional N-uptake compared to sole cropped *peas*. *Peas* in mixture with *white mustard* were strongly suppressed and are very low yielding. In mixture with *false flax,* yield decrease of the *peas* in the year 2004 was more moderate. But *peas* produced their biomass with higher N-efficiency. *Blue lupins* were dominated by *safflower* in mixed cropping systems. Lupin yields were strongly suppressed. No effects on N-contents and efficiency were found. In mixtures of legumes with oil crops with RYT >1*(peas x false flax),* the N-uptake of the mixtures is equivalent to or exceeds the N-requirement of the oil crops.

Literature

Aufhammer W (1999) Mischfruchtanbau von Getreide und anderen Körnerfruchtarten. Ulmer Stuttgart.

Bergmann W (1993) Ernährungsstörungen bei Kulturpflanzen. Gustav Fischer Verlag, Jena, Stuttgart.

Connolly J (1986) On difficulties with replacement-series methodology in mixture experiments. Journal of Applied Ecology, 23, 125–137.

Fujita K, Ofosu-Budu K G and Ogata S (1992) Biological nitrogen fixation in mixed legume-cereal cropping systems. Plant and Soil 141, 1-2, 155 - 175.

Hauggaard-Nielsen H and Jensen E S (2005) Facilitative Root Interactions in Intercrops. Plant and Soil 274, 237 – 250.

Høgh-Jensen H and Schjoerring J K (2000) Below-ground nitrogen transfer between different grassland species: Direct quantification by 15N leaf feeding compared with indirect dilution of soil 15N. Plant and Soil 227, 171-183.

Heikal M M D (1977) Physiological studies on salinity VI. Changes in water content and mineral composition of some plants over a range of salinity stresses, Plant and Soil, Volume 48, Issue 1, Sep 1977, Pages 223 – 232.

Honermeier B and Agegnehu M (1994) Zur Anbaueignung von Sommerleindotter (Camelina sativa Crtz). Mitt. Ges. Pflanzenbauwiss. 7, 331-334.

Jolliffe PA, Minjas A N and Runeckles V C (1984) A reinterpretation of yield relationships in replacement series experiments. Journal of Applied Ecology, 21, 227–243.

Kirsten, W (1983) Organic elemental analysis: Ultramicro, micro, and trace methods. Academic Press/Harcourt, Brace Jovanovich, New York

Lienemann K (2002) Incidence of Fusarium species in winter wheat in the Rhineland and possibilities of control with special reference to wheat cultivar. Dissertation Institute for Plant Diseases, Rheinische Friedrich-Wilhelms-University of Bonn

Moll R H, Kamprath, E J and Jackson W A (1982) Analysis and interpretation of factors which contribute to efficiency of nitrogen utilisation. Agron. J. 74, 562-564.

Paulsen H M, Rahmann G (2004) Wie sieht der energieautarke Hof mit optimierter Nährstoffbilanz im Jahr 2025 aus? Landbauforsch Völkenrode SH 274, 57-73.

van Ruijven J and Berendse F (2005) Diversity–productivity relationships: Initial effects, long-term patterns, and underlying mechanisms. PNAS 102,3 695-700.

Schmidke K and Rauber R (2000) Stickstoffeffizienz von Leguminosen im Ackerbau. In: Möllers C. (Hrsg.) (2000) Stickstoffeffizienz landwirtschaftlicher Kulturpflanzen. Erich Schmidt Verlag, Berlin, 48-69.

Snaydon R W (1991) Replacement or additive designs for competition studies. J. Appl. Ecol. 28, 930-946.

Trenbarth B R (1986) Resource use by intercrops. In: Francis C A (ed.) Multiple cropping systems, 57-81, Mac Millan, New York.

de Wit C T (1960) On Competition. Versl. Landbouwk. Onderz. 66.8.

de Wit C T and van den Berg J P (1965) Competition between herbage plants. Neth. J. Agric. sci. 13, 212-221.