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Effects of intercropping on yield, weed incidence, forage quality and soil residual N in organically grown forage maize (*Zea mays* L.) and faba bean (*Vicia faba* L.)

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ABSTRACT

This study investigated the effects of intercropping organically grown maize and faba bean under Swedish conditions on yield, forage quality, soil mineral nitrogen (N) content after harvest and weed incidence. Experiments with maize and faba bean as a monocrop and intercrop were performed at three field sites, with various amounts of N (dairy slurry) applied. The land equivalent ratio (LER) was 1.10–1.21 in two of the three experiments. The mean crude protein concentration of the three experiments increased from 63 g kg^{-1}, in feed of monocropped maize, to 107 g kg^{-1}, in feed of maize intercropped with faba bean. Intercropping had lower N balances compared with monocropped maize and tended to reduce the content of mineral N in the soil after harvest by, on average, 10 kg ha^{-1}. Weed incidence was slightly reduced by intercropping compared with monocropped maize. In conclusion, the results show that intercropping maize and faba bean in organic production can generate positive yield effects with LER > 1. Furthermore, intercropping resulted in higher protein content and lower residual soil mineral N after harvest compared to monocropped maize. Intercropping can thus increase the sustainability of forage production by reducing the need for protein feed and the risk of N pollution. The positive effects of intercropping, *i.e.* increased yield and reduced soil residual N, were found in the fields with relatively high amount of available N, but not in a field with lower N availability.

1. Introduction

Forage maize (*Zea mays* L.) is produced in many countries worldwide and is a common forage crop in southern Sweden. Maize has a high content of digestible starch, water-soluble carbohydrates (WSC) and fibre, creating a high energy feed suitable for ruminants when harvested at the recommended maturity stage (Masoero et al., 2006; Nadeau et al., 2010). However, supplementation of protein feed to high producing ruminants is required, since the crude protein content of maize is relatively low. In Sweden, imported soybean (*Glycine max* L. Merr.) has long been used as a protein supplement. The price of soybean has fluctuated widely recently, causing insecurity among farmers. In addition, soybean production may result in deforestation and also long transport distances, causing emissions of greenhouse gases (Morton et al., 2006). Therefore there is growing interest in locally produced protein crops, such as peas (*Pisum sativum* L.) and faba bean (*Vicia faba* L.). Environmentally sound or organic production systems aim to produce feed on the farm in order to achieve efficient nutrient cycling at farm level (Cederberg and Mattson, 2000; Cederberg et al., 2005).

Intercropping maize and various legumes for silage has been investigated with species such as soybean (*G. max* L. Merr.) in Canada (Martin et al., 1998), cow pea (*Vigna unguiculata* L.) in Iran (Dahmardeh et al., 2009) and various species of bean in the U.S. (Bryan and Peprah, 1988; Armstrong et al., 2008; Contreras-Govea et al., 2009). Intercropping commonly leads to a higher protein content in the forage compared with monocropped maize and higher yields on a land equivalent ratio (LER > 1) basis compared with monoculture (Bryan and Peprah, 1988; Martin et al., 1990; Armstrong et al., 2008; Dahmardeh et al., 2009). Intercropping faba bean and maize for silage in conventional production is possible under Swedish conditions and the forage quality is improved, with

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Table 1
Sites and locations of field experiments, soil properties and dates of sowing.

Locations of field experiments		Soil properties in topsoil (0–0.25 m)						Sowing date
Name of site, year	Longitude, latitude	pH	Organic matter (%)	Clay content (%)	Mineral N[a] ($kg\,ha^{-1}$)	P-AL ($mg\,kg^{-1}$)	K-AL ($mg\,kg^{-1}$)	
Nöbbelöv (NL), 2010	55°57′ N, 14°2′ E	6.6	4.9	11	25	260	210	20 May
Helgegården (HG), 2011	56°1′ N, 14°4′ E	7.9	1.4	6	32	390	120	1 May
Björkhaga (BH), 2011	56°4′ N, 13°57′ E	7.1	3.1	6	76	200	250	1 May

[a] NO_3-N and NH_4-N in 0–0.60 m soil layer.

slightly higher protein content and higher *in vitro* organic matter digestibility (Stoltz et al., 2013).

Plant nutrient uptake can be improved by intercropping (Li et al., 2001; Li et al., 2003). Nitrogen (N) transfer from the N-fixing legume to the maize and other species has also been reported (Martin et al., 1991a,b; He et al., 2009), reducing the need for N fertiliser. Growing plant species with differing root architecture in the same field also can increase nutrient use efficiency. For example, the residual nitrate concentration is reported to be reduced after harvest of maize intercropped with water convolvulus (*Ipomoea aquatic* Forsk.) compared with the crops in monoculture (Zhang and Li, 2003). Thus, intercropping may be an important strategy to use N efficiently and to reduce the risks of N leaching.

Maize has a low competitive ability in the beginning of the growing period, from 3- to 14-leaf stage (Hall et al., 1992). Weed control during this period is therefore crucial, especially in organic production, where the use of herbicides is prohibited. Increasing plant density is one way to increase the competitiveness of maize against weeds (Tollenaar et al., 1994). Increasing plant density with a companion crop may also be a way to reduce the amount of weeds in the crop. The incidence of weeds in common bean (*Phaseolus vulgaris* L.) crop was reduced when strip intercropped with maize and wheat (*Triticum aestivum* L.) compared with sole crop (Glowacka, 2010). Earlier studies showed that tall and relatively narrow species, such as faba bean and phacelia (*Phacelia tanacetifolia* Benth.), exert minimal competition against maize and maximal competition against weeds and are, thus, suitable as companion crops with maize (Jørgensen and Møller, 2000).

1.1. Objective and hypotheses

The objective of this study was to investigate the effects of intercropping maize and faba bean in organic production under Swedish conditions on yield, forage quality, content of mineral N in the soil after harvest and incidence of weeds. The hypotheses were that: (1) intercropping maize and faba bean for silage will increase yield with LER > 1 and (2) decrease the presence of weeds compared with monocrops; (3) intercropping of maize and faba bean will increase the protein concentration of the crop compared with monocropped maize; and (4) intercropping reduces the risk of N leakage after harvest compared with monocropping.

2. Materials and methods

2.1. Field experiments

Field experiments were performed at three sites in south-east Sweden (Table 1), one in 2010 (Nöbbelöv (NL)) and two in 2011 (Helgegården (HG) and Björkhaga (BH)), as on-farm trials by the Field Research Unit of the Swedish Rural Economy and Agricultural Societies (Hushållningssällskapet, Kristianstad). Composite topsoil samples were taken for determination of pH (Swedish standard (SS) ISO 10390), P-AL, K-AL (SS 028310/SS 028310T1), organic matter (KLK1965:1), soil texture (SS ISO 11277 mod.) and mineral N (ADAS method 53) (Eurofins Food and Agri Sweden AB, Kristianstad). Soil properties and sowing dates are shown in Table 1 and meteorological conditions in Table 2.

Table 2
Mean temperature (°C) and precipitation (mm) in May–September 2010 and 2011 in the area of the field experiments.

	2010		2011	
	Temperature	Precipitation	Temperature	Precipitation
May	10	52	11	60
June	14	46	15	80
July	19	42	17	128
August	17	70	16	111
September	12	81	14	44

An early hybrid (FAO 190) of maize (*Z. mays* L. cv. Isberi) and a late-maturing cultivar of faba bean (*V. faba* L. cv. Aurora) were either cultivated as monocrops or intercropped. Nitrogen was applied at 60 or 120 $kg\,ha^{-1}$ (60N or 120N) in the monocropped maize treatment (MM), 0 or 60 $kg\,ha^{-1}$ (0N or 60N) in the monocropped faba bean treatment (MFB) and 60 $kg\,ha^{-1}$ in the intercrop treatment (Intercrop 60N). Thus there were five treatments, each with four field replicates (in total 20 plots in each experiment), in a randomised complete block design. Each plot was 12 m long and 3 m wide *i.e.* the area of each plot was 36 m^2.

2.2. Cultivation practice

The crops were sown in mid-May in 2010 and in early May in 2011 in accordance with Swedish recommendations in all treatments (Table 1). Row spacing in maize was 0.75 m, seed rate was 85,000 viable seeds ha^{-1} and sowing depth was 0.04–0.05 m. Row spacing in faba bean was 0.12 m, seed rate was 700,000 viable seeds ha^{-1} and sowing depth was 0.05 m. In the intercrop treatment, one row of legumes was sown between the maize rows and thus the row width was 0.375 m. The seed rate in the intercrop was 85,000 viable seeds ha^{-1} in maize and 350,000 viable seeds ha^{-1} in faba bean. For all treatments, a four-row precision drill (Monosem, Edwardsville, KS, US) was used. The N was applied as cattle slurry, which is a commonly used fertiliser in organic production of maize in Sweden. An N meter for slurry (Agros Nova Mk3, Agros, Lidköping, Sweden) was used to estimate the NH_4-N content of the slurry and the dose adjusted accordingly. Thereafter, samples of slurry were taken and analysed for NH_4-N and total N (tot-N) according to Kjeldahl (KLK 65:1 (NH_4-N) and mod NMKL nr 6. Kjeltec (tot-N), Eurofins Food and Agri Sweden AB, Kristianstad. The N meter showed a lower value than the Kjeldahl analysis, so the amounts of NH_4-N applied in the treatments were higher than planned. The 60N and 120N treatments, of NH_4-N, received, respectively: 69 and 140 $kg\,N\,ha^{-1}$ at the NL site, 70 N and 140 $kg\,N\,ha^{-1}$ at the HG site and 86 and 172 $kg\,N\,ha^{-1}$ at the BH site, but are still referred to hereafter as 60N and 120N. Weeds were controlled in the field experiments by blind harrowing (twice in both years) before emergence, weed harrowing (none in 2010 and three times in 2011) and inter-row hoeing (twice in 2010 and three times in 2011). Inter-row hoeing was only performed in the treatments with maize and not in the MFB treatments.

2.3. Crop stands

The number of plants per hectare and plant height of faba bean were determined in mid-August (12–18 August). The number of faba bean plants was counted within two 2-m sections of a row in each experimental plot. Five randomly selected plants per plot were used for measuring plant height. In maize, the number of plants per hectare and plant height were determined at harvest in September–October by counting all harvested plants and measuring the height of five plants per experimental plot.

2.4. Weed

The fresh weight of weeds was determined within a $2 \times 0.25\,m^2$ area in each experimental plot in early July and mid-September.

2.5. Harvest

The aim was to harvest when the maize dry matter (DM) content was between 32 and 35% (early dent stage of maturity), which is optimum for silage maize (Bal et al., 1997; Phipps et al., 2000). Harvesting occurred on 27 September, 2010 and on 7–10 October, 2011. A $15\,m^2$ area of maize was harvested in each plot of the Intercrop and MM treatments using a single row maize chopper with scale wagon (JF MH 30, Denmark). The faba bean was harvested by hand at maturity stage 97–99 (Weber and Bleiholder, 1990; Lancashire et al., 1991) in a $4.5\,m^2$ area in the Intercrop treatment and a $2\,m^2$ area in the MFB treatment. All plants were cut at about 0.2 m above the ground and weighed on a field scale.

The LER was calculated as an indicator of the benefits of intercropping, according to:

$$\text{LER} = \frac{Y_{\text{ifb}}}{Y_{\text{mfb}}} + \frac{Y_{\text{im}}}{Y_{\text{mm}}}$$

where Y_{ifb} and Y_{mfb} are the forage yield per hectare of Intercrop 60N faba bean and MFB 0N, respectively, and Y_{im} and Y_{mm} are the forage yield per hectare of Intercrop 60N maize and MM 120N, respectively. In commercial organic growing, faba bean is not fertilised with N and around $120\,kg\,N\,ha^{-1}$ is used for maize. In addition to DM yield, yields of crude protein and of digestible organic matter (DOM) were calculated. The yield of DOM was calculated as DOM = (DM yield − ash yield) × *in vitro* organic matter digestibility (IVOMD).

2.6. Sampling and chemical analyses of crops

Crop samples were taken from each plot. Maize was chopped in a maize chopper (JF MH 30, Denmark) and faba bean in a compost mill (BOSCH AXT Rapid 2000).

For forage quality analyses, intercropped crops were mixed in the same ratio as the yield in all replicates. After thorough mixing, samples were taken (four replicates) from the MM 120N, MFB 0N and Intercrop 60N treatments. Dry matter content was determined after drying at 105 °C for 16 h. The concentrations of starch, crude protein, NH_4-N, neutral detergent fibre (NDF), IVOMD and ash were determined on samples dried at 60 °C for 16 h and ground in a mill (Karnas Kvarnmaskiner AB, Malmö, Sweden) to pass through an 1-mm screen (Eurofins Food and Agri Sweden AB, Lidköping, Sweden). Crude protein concentration was determined as total-N concentration using the Kjeldahl technique in a 2020 Digester and a 2400 Kjeltec Analyser Unit (FOSS Analytical A/S Hilleröd, Denmark). Ammonium-N concentration was determined using the FIA technique (Tecator, Application Note, ASN 50-01/92). Starch and WSC were analysed according to Larsson and Bengtsson (1983). The NDF concentration was analysed according to Chai and Udén (1998). The IVOMD was determined by incubating dried, milled samples in rumen fluid and buffer at 39 °C for 96 h (Lindgren, 1979; Åkerlind et al., 2011). Concentration of ash was determined at 550 °C for 16 h. In the two remaining treatments, MM 60N and MFB 60N, samples were taken for determination of DM as described above. The forage analyses were performed at Kungsängen Research Laboratory, Swedish University of Agricultural Sciences, Uppsala.

2.7. Soil N content and N balance

Soil samples were taken after harvest from the 0–0.30 m soil layer (six sub-samples per plot) and 0.30–0.60 m layer (three sub-samples per plot) in treatments MM 120N, MFB 0N and Intercrop 60N. The soil samples were analysed for mineral N, *i.e.* ammonium nitrogen (NH_4-N) and nitrate-N (NO_3-N) as described above.

Two N balances ($kg\,ha^{-1}$) were estimated by using either the content of total N (mineral and organically bound N) or by using the content of NH_4-N as input from the slurry. The N balances were defined as

$$\text{Balance}_{(\text{tot N input})} = \text{input}_{(\text{totN})} - (\text{output in crop} + \text{soil residual N})$$

$$\text{Balance}_{(\text{NH}_4\text{-N input})} = \text{input}_{(\text{NH}_4\text{-N})} - (\text{output in crop} + \text{soil residual N})$$

where the input was the mineral N content in soil at sowing + total N or NH_4-N content of the slurry; the output was the total N content in the crop; and the soil residual N was the mineral N in the soil after harvest.

2.8. Statistical analyses

Statistical analyses were performed with JMP 9.0 (SAS Institute, 2010) using a mixed linear model with 'treatment', 'experimental site' and the interaction 'treatment × experimental site' as fixed factors and 'block (experimental site)' as a random factor. There were four blocks per treatment. When the *F*-value was significant for the main effects and interactions of the fixed factors, pair-wise comparisons with Tukey's HSD-test were performed to identify significant differences ($p < 0.05$) between treatment means.

3. Results

All the results presented are statistically significant ($p < 0.05$) unless otherwise stated.

3.1. Crop stand and weed incidence

On average over the three field sites, the number of maize plants per hectare was approx. 13% lower and plant height approx. 0.45 m lower in the Intercrop treatment than in the two MM treatments (Table 3). The average number of faba bean plants per m^2 was approx. 66% lower and plant height approx. 0.1 m greater in the Intercrop treatment than in the two MFB treatments. On average over treatments, the number of maize plants per hectare was higher and the number of faba bean plants per m^2 was lower at NL than at the other two field sites. Regarding plant height of maize and faba bean, the sites were in the order: BH > HG > NL (Table 3). There was a significant interaction between the main effects for the number of plants per m^2 and plant height in faba bean (Table 3). The number of plants per m^2 in the Intercrop treatment was 35% at NL, 31% at HG and 33% at BH, of that of the MFB treatments. The plant height in the Intercrop treatment was increased by 25% at NL, 4% at HG and 8% at BH compared with MFB treatments.

Table 3
Crop stand and incidence of weeds in different cropping systems with various levels of nitrogen at three field experiment sites.

Main effects and interaction	Maize		Faba bean		Weeds	
	No. plants (plants ha^{-1})	Plant height (cm)[3]	No. plants (plants m^{-2})	Plant height (cm)[4]	July ($g\,m^{-2}$)	September ($g\,m^{-2}$)
Treatment n = 12 (crops), 20 (weeds)						
MM 120N	56,407[a]	270[a]			635[ab]	721[a]
MM 60N	56,593[a]	260[a]			759[a]	594[ab]
Intercrop 60N	48,962[b]	218[b]	21[b]	120[a]	556[ab]	354[ab]
MFB 60N			65[a]	109[b]	399[b]	318[b]
MFB 0N			63[a]	110[b]	344[b]	305[b]
SEM treatment	1425	4.1	2.2	2.5	0.2	0.2
p (treatment)	<0.001	<0.001	<0.001	<0.001	0.006	0.003
Site n = 12 (crops), 20 (weeds)						
NL	62,685[a]	200[c]	38[b]	71[c]	419	1006[a]
HG	51,000[b]	256[b]	60[a]	126[b]	439	274[b]
BH	48,278[b]	291[a]	51[a]	142[a]	749	288[b]
SEM site	1425	4.3	2.4	2.5	0.2	0.14
p (site)	<0.001	<0.001	<0.001	<0.001	ns	<0.001
Treatment × site n = 4						
NL						
MM 120N	66,389	225			507	1047[ab]
MM 60N	64,444	215			619	974[ab]
Intercrop 60N	57,222	161	17[e]	81[d]	322	936[abc]
MFB 60N			55[bc]	69[de]	363	1222[a]
MFB 0N			42[cd]	61[e]	352	881[abc]
HG						
MM 120N	50,833	279			630	378[abcd]
MM 60N	52,833	260			957	308[abcd]
Intercrop 60N	49,333	230	24[de]	130[bc]	397	199[cd]
MFB 60N			76[a]	121[c]	361	283[abcd]
MFB 0N			81[a]	128[bc]	189	238[bcd]
BH						
MM 120N	52,000	307			801	946[abc]
MM 60N	52,500	304			737	699[abc]
Intercrop 60N	403,333	263	22[e]	149[a]	1346	238[bcd]
MFB 60N			64[ab]	135[bc]	482	92[d]
MFB 0N			68[ab]	140[ab]	613	135[d]
SEM treatment × site	2469	7.1	3.8	3.3	0.3	0.3
p (treatment × site)	ns	ns	0.005	0.032	ns	0.005

MM = monocrop maize, MFB = monocrop faba bean; 0N, 60N, 120N = 0, 30, 60 kg N ha^{-1}.
NL = Nöbbelöv, HG = Helgegården, BH = Björkhaga.
SEM = standard error of the mean.
Different superscripts within columns indicate significant differences between means of the main effects of treatment and site and their interaction ($p < 0.05$).

The effect of cropping regime on weed incidence was similar in July and September (Table 3). Mean weed biomass at all three field sites was generally highest in the MM treatment (594–759 $g\,m^{-2}$) and lowest in the MFB treatment (305–399 $g\,m^{-2}$), while the Intercrop treatment gave intermediate results (354–556 $g\,m^{-2}$). In July, there were no differences in weed biomass between the field sites, while the weed incidence was highest at NL in September (Table 3). There was an interaction between the main effects for weed biomass in September, but not in August. There were no significant differences between the treatments in the weed biomass at NL and HG. At BH, the MFB treatments had significantly lower weed biomass than the MM treatments (Table 3).

3.2. Yield

The maize yield (mean of the three sites) was larger in the MM 60N treatment than in Intercrop 60N and increased with increasing N rate in the MM treatments (Table 4). Faba bean yield was higher in the MFB treatments than in Intercrop 60N. The crude protein yield was higher in the Intercrop 60N treatment than in MM 120N, but not higher than in MFB 0N The digestible organic matter (DOM) yield was largest in the MM 120N and larger in the Intercrop 60N than in the MFB 0N. Furthermore, the DOM yield was larger at HG and BH than at NL as a mean over treatments. The yield of DOM of MM 120N was larger than of the Intercrop 60N at BH but not at NL and HG, whereas the MFB 0N had the lowest DOM yield at all three sites.

Yields of DM, crude protein and DOM were lower at NL than at the other two field sites (Table 4). There was a significant interaction between the main effects for yields of faba bean and of crude protein, but not for yield of maize. The faba bean yield in the Intercrop N60 was 56%, 36% and 69% of the MFB treatments at NL, HG and BH respectively. At HG, the protein yield was significantly higher in the MFB 0N than in the MM 120N, whereas no significant differences between the treatments were found at the other sites (Table 4). At NL and BH, the faba bean accounted for a greater share of the total protein yield (56%) than the maize (44%) in the intercropped treatment, while the opposite was found at HG, where 53% of the protein was achieved from maize and 47% from faba bean.

The LER of DM was >1 at NL and BH. The LER of faba bean varied between 0.58 and 0.65 and that of maize between 0.51 and 0.56 at the NL and BH sites, so the final LER was 1.10–1.21. At the HG site, the LER of faba bean was 0.35, that of maize was 0.63 and total LER was 0.98. There were no significant differences for LER of maize and total LER between the sites. LER for faba bean was significantly ($p < 0.025$) lower at HG (0.35) than at BH (0.65).

3.3. Forage quality

At all three sites, the content of DM was highest in treatment MFB 0N, whereas the Intercrop 60N and MM 120N treatments had similar DM contents, when averaged over sites (Table 5). The IVOMD was higher in the MM 120N and Intercrop 60N treatments than in MFB 0N at all sites. The IVOMD was higher at HG than at BH,

Table 4
Yields of dry matter (DM), crude protein and digestible organic matter (DOM) of silage maize and faba bean, in different cropping systems with various levels of nitrogen at three field experiment sites.

Main effects and interaction	DM maize (kg ha^{-1})	DM faba bean (kg ha^{-1})	Crude protein (kg ha^{-1})	DOM (kg ha^{-1})
Treatment *n* = 12				
MM 120N	12,698^{a}		809^{b}	9875^{a}
MM 60N	11,296^{b}			
Intercrop 60N	7178^{c}	2381^{b}	994^{a}	7398^{b}
MFB 60N		4263^{a}		
MFB 0N		4849^{a}	951^{ab}	3102^{c}
SEM treatment	413.8	211.5	48.2	328.7
p (treatment)	<0.001	<0.001	0.030	<0.0001
Site *n* = 12				
NL	6727^{b}	2283^{b}	609^{b}	4702^{b}
HG	11,299^{a}	4633^{a}	1063^{a}	7526^{a}
BH	13,148^{a}	4575^{a}	1083^{a}	8147^{a}
SEM site	489.1	264.8	50.7	328.7
p (site)	<0.001	<0.001	<0.001	<0.001
Treatment × site *n* = 4				
NL				
MM 120N	8651		565^{c}	7327^{cd}
MM 60N	7321			
Intercrop 60N	4209	1496^{c}	659^{c}	4781de
MFB 60N		2690^{cd}		
MFB 0N		2665^{cd}	602^{c}	1999^{f}
HG				
MM 120N	13,801		784^{bc}	10,231^{ab}
MM 60N	11,543			
Intercrop 60N	8553	2129^{cd}	1095^{ab}	8255^{bc}
MFB 60N		5438^{a}		
MFB 0N		6333^{a}	1311^{a}	4091^{ef}
BH				
MM 120N	15,644		1077^{ab}	12,067^{a}
MM 60N	15,031			
Intercrop 60N	8771	3518^{bc}	1229^{a}	9157^{bc}
MFB 60N		4658^{ab}		
MFB 0N		5549^{a}	943^{abc}	3215^{ef}
SEM treatment × site	716.8	366.3	83.5	569.3
p (treatment × site)	ns	0.001	0.008	0.030

MM = monocrop maize, MFB = monocrop faba bean; 0N, 60N, 120N = 0, 60, 120 g N ha^{-1}.
NL = Nöbbelöv, HG = Helgegården, BH = Björkhaga.
SEM = standard error of the mean.
Different superscripts within columns indicate significant differences between means of the main effects of treatment and site and their interaction ($p < 0.05$).

while that at NL was intermediate and did not differ from the other two sites. Furthermore, the Intercrop 60N treatment had higher IVOMD than the MM 120N at HG whereas there were no significant differences between treatments at the two other sites. The ash content of the crops decreased in the following order: MFB 0N > Intercrop 60N > MM 120N and the ash content was higher at HG than at NL and BH. The mean WSC content of the three treatments decreased in the order: MM 120N > Intercrop 60N > MFB 0N. There were significant interactions between treatment and site for WSC and starch contents. The MFB 0N had the lowest WSC content among the treatments at all three sites and the MFB 0N had the lowest starch content at HG and BH but there were no differences in starch content between the treatments at NL. The content of WSC was highest and the starch content was lowest at site NL, when averaged over treatments. The mean NDF content was highest in the MFB 0N treatment but there was a significant interaction between main effects due to variation between sites. The NDF content was higher at BH than at the other two sites. The crude protein concentration of the crops decreased in the order: MFB 0N > Intercrop 60N > MM 120N at all sites. Site NL had higher crude protein concentration than the other two sites (Table 5).

3.4. Residual soil N

There were no differences in mean residual NH_4-N between the treatments in the 0–0.30 m or 0.30–0.60 m soil layer after harvest (Table 6). The residual NO_3-N in the 0–0.30 m layer after harvest was higher in MM 120N than in the other treatments at BH, whereas no differences between treatments were found at NL and HG. In the 0.30–0.60 m soil layer, the mean residual NO_3-N decreased in the order MFB 0N > MM 120N > Intercrop 60N (Table 6). The total residual mineral N after harvest was higher for MM 120N than for the other treatments at BH, but there were no differences between treatments at the other two sites. The amount of NH_4-N in the 0–0.30 m layer and total mineral N in the 0–0.60 m layer was significantly lower at HG than at NL.

3.5. N balances

In both N balances, the highest values were found in the treatment with MM 120N followed by the Intercrop 60N and the lowest values were found in the MFB 0N treatment (Table 7). When the calculation was based on the amount of NH_4-N in the slurry, the Intercrop 60N treatment had a negative value, but when using the total amount of N the value was positive. The ranking of N balances at various sites was as follows: BH > NL > HG.

4. Discussion

4.1. Yield

At two of the three experimental sites, LER was >1, supporting hypothesis 1. The LER of 1.10–1.21 at the NL and BH sites was slightly lower than the 1.21–1.23 reported by Li et al. (1999) on comparing total yields of maize and faba bean in intercrop and monocrop systems. However, in that study both systems received

Table 5
Forage quality parameters in cropping systems with monocropped and intercropped faba bean and maize at three field experiment sites.

Main effects and interaction	DM (%)	IVOMD (%)	Ash (g kg^{-1} dm)	WSC (g kg^{-1} dm)	Starch (g kg^{-1} dm)	NDF (g kg^{-1} dm)	Crude protein (g kg^{-1} dm)
Treatment *n* = 12							
MM 120N	30.7^{b}	88.0^{a}	35.2^{c}	134^{a}	291^{a}	399^{b}	63^{c}
Intercrop 60N	34.7^{b}	89.0^{a}	44.1^{b}	92^{b}	260^{b}	390^{b}	107^{b}
MFB 0N	63.6^{a}	74.9^{b}	54.2^{a}	20^{c}	183^{c}	434^{a}	202^{a}
SEM treatment	1.90	0.58	1.40	3.9	8.8	5.989	3.1
p (treatment)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Site *n* = 12							
NL	39.4	84.6^{ab}	41.2^{b}	101^{a}	201^{b}	392^{b}	137^{a}
HG	43.2	85.3^{a}	48.8^{a}	70^{b}	275^{a}	391^{b}	122^{b}
BH	46.4	82.1^{b}	43.5^{b}	74^{b}	258^{a}	440^{a}	112^{b}
SEM site	2.00	0.63	1.40	3.9	9.9	6.0	3.7
p (site)	ns	0.014	0.002	<0.001	0.001	<0.001	0.004
Treatment × site *n* = 4							
NL							
MM 120N	25.4	87.3^{ab}	30.2	171^{a}	229^{bc}	406^{b}	65^{d}
Intercrop 60N	29.4	87.1^{ab}	44.3	113^{b}	182^{c}	401^{bc}	119^{c}
MFB 0N	63.2	79.2^{c}	49.1	20^{d}	190^{c}	368^{bc}	227^{a}
HG							
MM 120N	33.9	86.1^{b}	39.5	115^{b}	307^{a}	408^{b}	56^{d}
Intercrop 60N	37.6	91.8^{a}	44.4	75^{c}	325^{a}	353^{c}	103^{c}
MFB 0N	58.2	78.1^{c}	62.4	20^{d}	193^{c}	411^{b}	208^{a}
BH							
MM 120N	32.7	90.7^{ab}	35.8	116^{b}	336^{a}	383^{bc}	69^{d}
Intercrop 60N	37.1	88.1^{ab}	43.8	88^{bc}	273^{ab}	415^{b}	100^{c}
MFB 0N	69.2	67.5^{d}	51.1	20^{d}	166^{c}	523^{a}	169^{b}
SEM treatment × site	3.309	1.01	2.43	6.7	15.2	10.4	5.4
p (treatment × site)	ns	<0.001	ns	0.001	<0.0001	<0.001	<0.001

MM = monocrop maize, MFB = monocrop faba bean; 0N, 60N, 120N = 0, 60, 120 kg N ha^{-1}.
NL = Nöbbelöv, HG = Helgegården, BH = Björkhaga.
IVOMD = *in vitro* rumen organic matter digestibility.
WSC = water-soluble carbohydrates.
NDF = neutral detergent fibre.
SEM = standard error of the mean.
Different superscripts within columns indicate significant differences between means of the main effects of treatment and site and their interaction ($p < 0.05$).

Table 6
Mineral nitrogen (N) concentration in the 0–0.30, 0.30–0.60 and 0–0.60 m soil layers in cropping systems with monocropped and intercropped faba bean and maize at three field experiment sites.

Main effects and interaction	Soil layer				
	0–0.30 m		0.30–0.60 m		0–0.60 m
	NH_4-N (kg ha^{-1})	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	NO_3-N (kg ha^{-1})	tot-N (kg ha^{-1})
Treatment *n* = 12					
MM 120N	9.6	20^{a}	2.6	10.5^{b}	42.6^{a}
Intercrop 60N	10.3	12^{b}	2.3	6.4^{c}	31.3^{b}
MFB 0N	9.0	16^{ab}	2.1	15.8^{a}	42.8^{a}
SEM treatment	0.578	1.60	0.24	0.96	2.26
p (treatment)	ns	0.012	ns	<0.001	0.001
Site *n* = 12					
NL	10.1^{b}	7^{b}	4.2^{b}	5.9^{b}	27.2^{b}
HG	4.6^{c}	6.6^{b}	1.3^{b}	5.8^{b}	18.4^{c}
BH	14.1^{a}	34.7^{a}	1.4^{a}	21.0^{a}	71.2^{a}
SEM site	0.738	1.69	0.24	1.01	2.26
p (site)	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment × site *n* = 4					
NL					
MM 120N	10.3	6.0^{c}	4.8	4.2	25.3^{cd}
Intercrop 60N	10.9	5.3^{c}	4.1	3.6	23.8^{cd}
MFB 0N	9.0	9.9^{c}	3.7	9.8	32.4^{c}
HG					
MM 120N	4.3	3.5^{c}	1.2	4.2	12.1^{d}
Intercrop 60N	4.75	4.2^{c}	1.5	1.5	11.8^{d}
MFB 0N	4.9	12.2^{c}	1.3	11.8	30.1^{cd}
BH					
MM 120N	14.2	50.5^{a}	1.8	23.0	89.4^{a}
Intercrop 60N	15.2	27.8^{b}	1.3	14.1	58.4^{b}
MFB 0N	13.0	25.9^{b}	1.3	25.8	65.9^{b}
SEM treatment × site	1.00	2.78	0.419	1.67	3.91
p (treatment × site)	ns	<0.001	ns	ns	<0.001

MM = monocrop maize, MFB = monocrop faba bean; 0N, 60N, 120N = 0, 60, 120 kg N ha^{-1}.
NL = Nöbbelöv, HG = Helgegården, BH = Björkhaga.
SEM = standard error of the mean.
Different superscripts within columns indicate significant differences between means of the main effects of treatment and site and their interaction ($p < 0.05$).

Table 7
Estimation of N balances (based on input of NH_4-N and tot-N content in slurry) in cropping systems with monocropped and intercropped faba bean and maize at three field experiment sites. N balance = input (mineral N in soil + N in slurry) − N in crop + mineral N in soil after harvest.

Main effects and interaction	N balances (kg ha^{-1})	
	NH_4-N input	tot-N input
Treatment *n* = 12		
MM 120N	108[a]	255[a]
Intercrop 60N	−8.50[b]	64.4[b]
MFB 0N	−65.1[c]	−65.1[c]
SEM treatment	8.37	8.37
p (treatment)	<0.001	<0.001
Site *n* = 12		
NL	24.4[b]	108[b]
HG	−50.4[c]	−0.921[c]
BH	60.4[a]	147[a]
SEM site	8.64	8.64
p (site)	<0.001	<0.001
Treatment × site *n* = 4		
NL		
MM 120N	99.8	268
Intercrop 60N	12.3	95.1
MFB 0N	−38.9	−38.9
HG		
MM 120N	58.3	157
Intercrop 60N	−62.0	−12.5
MFB 0N	−148	−148
BH		
MM 120N	166	339
Intercrop 60N	24.2	111
MFB 0N	−8.94	−8.94
SEM treatment × site	14.495	14.495
p (treatment × site)	ns	ns

MM = monocrop maize, MFB = monocrop faba bean; 0N, 60N, 120N = 0, 60, 120 kg N ha^{-1}.
NL = Nöbbelöv, HG = Helgegården, BH = Björkhaga.
SEM = standard error of the mean.
Different superscripts within columns indicate significant differences between means of the main effects of treatment and site and their interaction ($p < 0.05$).

the same amount of fertiliser. The LER would have been higher in the present study if the treatments with 60N had been used in the calculation (LER_{NL} = 1.12, LER_{HG} = 1.13, LER_{BH} = 1.36, data not shown), but this is not likely to be found in practical farming.

Maize was affected by competition from the faba bean plants since the maize yield was reduced by intercropping despite similar plant densities of the monocropped and intercropped maize treatments (Table 3). Maize is sensitive for competition in the beginning of the season (Hall et al., 1992), and may have been affected by the rapid growth of faba bean. Faba bean was positively affected by intercropping at NL and BH with larger plants and a LER > 0.5 even though the plant density was less than 50% of the MFB 0N treatment.

The low LER of 0.98 at HG was due to the low LER for faba bean of 0.35, which in turn was due to small plants and the slightly lower number of faba bean plants per m^2 in the intercrop in relation to the MFB 0N treatment. At NL and BH, the faba bean seemed to be favoured by intercropping and the plants were larger than in the MFB treatments. At HG, the plants were similar in size in all treatments. The differences in faba bean response to intercropping between the sites might be due to the access of N. At HG, the access of N was low with negative N balances for both Intercrop 60N and MFB 0N, which was not the case for the other two sites (Table 7). The competition for N from the maize might have affected the faba bean plants at HG.

The results showed that the existing cultivation recommendations should not be changed, since the yield in the MM 60N treatment was lower than in MM 120N and there was no increase in yield in MFB 60N compared with MFB 0N. Although there was a negative nitrogen balance for the MFB 0N, the faba bean cultivation without nitrogen fertilisation will be sustainable as it fixates atmospheric N_2.

4.2. Crop stand

At sowing, the seed rate of the intercropped faba bean was planned to be 50% of that in the MFB, but the outcome was much lower (Table 3). This was probably due to the great row spacing (0.75 m) between the faba bean rows in the Intercrop treatment causing a high number of seeds in the row, which may be difficult to accomplish in practice. Furthermore, the inter-row hoeing had to be performed much closer to the seed row in the Intercrop treatments, with a row spacing of 0.375 m, compared with monocropped maize, with a row spacing of 0.75 m. Hence some plants in the Intercrop treatment might have been damaged. The plant damage by hoeing was probably also the reason to the lower number of maize plants found in the Intercrop treatment compared with MM. Intercropping had a beneficial effect on faba bean yield at NL and HG, despite the fact that the number of faba bean plants per unit area was lower in Intercrop compared with monocrop treatments. In previous studies on intercropping, row spacing has varied and weed control has been by herbicide application or hand weeding (Martin et al., 1998; Armstrong et al., 2008; Dahmardeh et al., 2009), which does not affect the number of plants per m^2. The cropping system in the present study was designed to enable weed treatment with agricultural machinery, *i.e.* inter-row hoeing.

4.3. Weed incidence

Maize is especially influenced by weeds emerging at the beginning of the growing season (Hall et al., 1992), while late emerging weeds have less impact on maize yield (Murphy et al., 1996). The presence of weeds was slightly reduced by intercropping compared with MM but not compared with MFB, only partly supporting hypothesis 2. At all experimental sites, MFB had the lowest amount of weed biomass, confirming that weed treatments are not commonly needed in organic faba bean cultivation (Table 3). There was one exception; at NL the weed biomass was relatively high in the MFB treatment, probably due to the poor crop stand and low number of plants. Thus, faba bean is an appropriate plant species to suppress weeds when intercropped with maize.

4.4. Quality of feed

The protein content increased from 63 g kg^{-1} in MM 120N to 107 g kg^{-1} in Intercrop 60N, supporting hypothesis 3. The greater increase in crude protein content (+44 g kg^{-1}) with intercropping compared with in our previous study (+10–15 g kg^{-1}; Stoltz et al., 2013) was probably due to the thorough mixing of the forage before collection of samples in the present study. There was a great difference in the DM content of the two crops at harvest, with the volume of maize being much greater than that of faba bean. The presence of a piece of a bean in the maize sample could have made a great difference.

The increase in crude protein content of the forage, on average 70% in the Intercrop 60N treatment compared with the MM 120N, contributed to a total higher protein yield of 185 kg ha^{-1} than in the MM 120N of 809 kg ha^{-1} (Table 4). The amount of digestible organic matter was decreased by 25% while the crude protein yield increased by 23% in the intercrop treatment compared to monocropped maize, when averaged over sites (Table 4). These changes in nutrient availability is important to consider for cattle producers as the amount of metabolisable protein that is needed for animal performance to a major extent originates from microbial protein in the rumen. The synthesis of microbial protein requires energy supply from the rumen fermentation of digestible carbohydrates (Merchen and Bourquin, 1994).

In general, intercropped maize and faba bean had intermediate contents of crude protein, WSC and starch compared to their monocropped counterparts. Thus, the forage of intercropped maize and faba bean has the potential to provide silage of good nutritional quality.

The contents of crude protein and NDF in the MM treatment were relatively low (56–69 and 383–408 g kg^{-1}, respectively) compared with results from previous studies of maize silage with similar DM contents (71–80 and 431–444 g kg^{-1}, respectively) (Bal et al., 1997; Phipps et al., 2000). The field experiment at the NL site was harvested slightly earlier than the other experiments, resulting in low DM and starch contents but a high WSC content in the MM 120N and in the Intercrop 60N treatment.

4.5. Residual soil N and N balances

Intercropping may be an important strategy to reduce leaching of residual mineral N (NO_3-N and NH_4-N) after harvest, which is a serious problem in maize production (Wiesler and Horst, 1993; Richards et al., 1999; Herrmann and Taube, 2005). The greatest effects were found at the BH site, with high mineral N soil content (Table 1) and a higher amount of slurry applied (see Section 2.2), where intercropping reduced soil mineral N after harvest by about 30 kg ha^{-1} compared with MM 120N (Table 6). Additionally, the N balances were lower in the Intercrop 60N treatment compared with MM 120N (Table 7). The negative values of the N balances may give an indication of the magnitude of N from the faba bean's N fixation. The residual soil N was on average lower in the Intercrop 60N treatment than in the MFB 0N treatment. Hence, the results supported hypothesis 4, *i.e.* that intercropping reduces the risk of N leakage compared with monocropping.

4.6. Conclusion

This study showed that intercropping maize and faba bean in organic production can generate positive yield effects with LER > 1 and reduce the risk of N leakage after harvest. Compared with monocropped maize, the crude protein content of the forage was increased by intercropping, with average total crude protein yield increase by 185 kg ha^{-1}. Furthermore, the incidence of weeds was slightly reduced in the intercropped compared to the monocropped maize. Thus, intercropping can increase the sustainability of forage production by reducing the need for protein feed and the risk of N pollution. The positive effects of intercropping on yield were found in the fields with relatively high amounts of available N, but not in a field with lower N availability.

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