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Nitrogen Utilization in Integrated Crop and Animal Production

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Key words: nitrogen utilization, nutrient circulation, integrated production

Abstract

The principles of organic production are based on integration between crop and animal production and self-regulated nutrient intensity. A comparison between specialized dairy and crop farm models and an integrated dairy and crop farm model showed 24 % higher total production per area and higher nitrogen utilization in the integrated system. The main factors were more efficient nutrient circulation, better utilization of legume crops and low intensity of nitrogen on non-legume crops.

Introduction

The main factors influencing nutrient utilization in agriculture are the production line (crop vs. animal production) and the degree of intensity and specialization of production. Organic production is based on integration between crop and animal production and self-regulated nutrient intensity. However, many organic farms are specialized in crop production based only on green manure and farm yard manure (FYM) from neighbouring farms. On the other hand, animal farms widely use purchased fodder. All of this may effect the utilization of nutrients, yet hardly any comparisons or analytical surveys between specialized and integrated (organic) farms can be found in literature.

The aims of this study were:
a) To model specialized organic crop and animal farms and an integrated farm
b) To identify the differences in nutrient balances and utilization between the models
c) To optimize nutrient utilization by means of integrating crop and animal production

Material and methods

A more detailed analysis was made of nitrogen (N) utilization on 9 organic farms in eastern Finland. The farmers were personally interviewed in 2004 and all the main nutrient flows were identified for the years 2002-2004. The assumption of a steady-state with balanced systems and reserve nutrients in the soil was applied. Biological N fixation (BNF) was assumed to account for 70 – 90 % of the total nitrogen content in the legume biomass (Kristensen et al. 1995, STANK 1998, Väisänen 2000). Red clover, white clover and alsike clover were grown in perennial mixture leys. Pea and annual vetch were annual legumes. (Seuri 2005).

Equal amounts of milk, beef and bread cereal were produced either on a specialized dairy farm (D) model and a specialized crop farm (C) model jointly or on an integrated dairy and crop farm (I) model. The share of fodder production was 80 % and bread cereal 20 % of the total yield, based on the average Finnish diet and use of arable land. BNF and atmospheric deposition (5 kg/ha annually) were the only external inputs of nitrogen (=primary nitrogen) in both systems. On farm C, all the harvested yield was

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sold (either to farm D as fodder or outside the system as bread cereal) and no FYM was used. On farm D, all the harvested yield was used as fodder. In addition, about 20 % of the fodder was purchased from farm C. All of the FYM was used only on farm D. On farm I, no fodder was purchased, but 20 % of total yield was sold as bread cereal.

Results

The major characteristics of the farm models are presented in Tables 1 and 2; more detailed N utilization is presented in Table 3.

Tab.1: Characteristics of three farm models: Specialized Dairy Farm (D), Specialized Crop Farm (C) and Integrated Dairy and Crop Farm (I). Both of the dairy farms (D & I) keep equal numbers of calves for replacement, all others are sold immediately after the suckling period. Replacement of the cows takes place after three milking periods.

	D	**C**	**I**
Crop rotation / (crops %)			
ley / green fallow	3 yrs. (60%)	2 yrs. (40%)	2 yrs. (40%)
cereals	2 yrs. (40%)	2 yrs. (40%)	2 yrs. (40%)
rape seed	-	1 yr. (20%)	-
cereal+peas	-	-	1 yr. (20%)
Legumes % / non-legumes %	60 / 40	40 / 60	60 / 40
Yield level (FU/ha & N kg/ha)			
ley /(green fallow)	3200 & 85	(green fallow)	3200 & 85
cereals	2200 & 42	2200 & 42	2000 & 38
rape seed	-	1800 & 42	-
cereal+peas	-	-	2000 & 52
Harvested N yield (kg/ha)	68	25	60
Animal density (AU/ha	0.71	-	0.43
Milk yield (kg/cow)	7350	-	7000

Tab. 2: Legume yields and BNF on farm models. C*, no legume yield is harvested, but ploughed in as green manure; only the first year ley exists (twice in 5-year-rotation) on farm C.

Crop	Farms D & C*	Farm I	Farms D, C & I
	Yield (FU/ha)	Yield (FU/ha)	BNF (N kg/ha)
First-year ley	3600	3400	120
Second-year ley	3200	3000	80
Third-year ley	2800	-	40
Cereal + peas	-	2000	40

The total average BNF is equal (48 kg/ha) in all the farm models. However, there is quite great variation between N intensity on non-legumes (=manure or green manure for non-legumes). The N intensity on non-legumes is highest on farm D (100 kg/ha), due to high amount of manure on a limited non-legume area (40%). Also on farm C the N intensity is higher (80 kg/ha) on non-legumes than on farm I (65 kg/ha). (Tab. 3).

Due to the lower N intensity on non-legumes, 10 % lower crop yield is assumed on farm I than on D and C (Tab. 1.).

Despite the lower yield level because of lower N intensity on non-legumes, the average total production is higher in integrated production (I) than in specialized production (D+C). More arable land, 24 %, is needed on the specialized farms than on the integrated farm to produce an equal "food basket" (milk, beef and (bread)cereal) (Tab. 3.). This is due to the green fallow on the specialized crop farm.

Tab. 3: N flows and balances in three model systems. Comparison by equal total production, I vs. D+C (sum of 0.57 ha D and 0.67 ha C equals 1 ha I); and by equal area (1 ha).

*Note: System boundaries are slightly different between EP and EA (**bolded** figures); e.g. purchased fodder in EP is not an input or output, but within system boundaries as it is purchased from farm C; in EA it is external input (farm D) and output (farm C).*

	symbol	unit	I (1 ha)	Equal production (EP) D+C (1.24 ha)	D (0.57 ha)	C (0.67 ha)	Equal area (EA) D (1 ha)	C (1 ha)
Harvested N yield[1]	Y	(kg N)	60	56	39	17	68	25
N intensity on non-legumes[2]		(kg N/ha)	65	89	100	80	100	80
Deposition	p_1	(kg N)	5	6	3	3	5	5
BNF	p_2	(kg N)	48	60	28	32	48	48
Total fodder	F	(kg N)	51	47	47		82	
Fodder harvested	F_h	(kg N)	51	-	39		68	
Fodder purchased	F_p	(kg N)		-	**8**		**14**	
FYM (=F-A-L)	M	(kg N)	26	23	23		40	
FYM (fodder harvested)	m	(kg N)	26	-	19		33	
FYM (fodder purchased)	p_3	(kg N)		-	**4**		**7**	
Losses outside field[3]	L	(kg N)	13	12	12		21	
Animal products sold	A	(kg N)	12	12	12		21	
Crop products sold	C	(kg N)	9	**9**		9 (+8)		25
Primary N (= $p_1+p_2+p_3$)	P	(kg N)	53	**66**	31	35	**60**	53
Secondary N (= $M-p_3$)	S	(kg N)	26	**23**	23		**33**	
Circulation factor (P+S)/P		(-)	1.49	**1.35**	1.75	1	**1.55**	1
Farm gate balance $p_1+p_2+F_p-C-A$		(kg N)	32	**45**			**46**	28
output/input (C+A)/($p_1+p_2+F_p$)		(-)	0.39	**0.32**			**0.32**	0.47
Field balance p_1+p_2+M-Y		(kg N)	19	**33**			**25**	28
output/input Y/(p_1+p_2+M)		(-)	0.76	**0.63**			**0.73**	0.47
PPB[4] = Y/P		(-)	1.13	**0.85**	1.25	0.47	**1.14**	0.47

1 See table 1.
2 FYM or green manure N for non-legumes
3 40 kg N/cow (incl. young cattle for replacement) (Grönroos et.al. 1998)
4 Primary production balance (Seuri 2005)

The nutrient balances describe the nutrient utilization, whereas comparison by area does not show any clear difference between the models. Comparison by equal total production indicates better utilization on the integrated farm than on the specialized farms jointly by all the indicator balances used (farm gate balance, field balance, PPB). The difference between primary N is 24 % (53 kg vs. 66 kg) for equal total production.

The major difference between these two production strategies is nutrient circulation. In the integrated system (I) the circulation factor of N is as high as 1.49. In the specialized system (D+C) it is clearly lower, 1.35. Another major difference is the poor field balance (0.47) in the specialized crop production compared to the field balance in the integrated system (0.76). This indicates the importance of utilization of legume

yield. On farm C, no legume yield is utilized as a final output of the system, but only as a source of N for a non-legume cash crop.

Conclusions

N intensity is highly dependent on the proportion of legume crops in the crop rotation. However, with increasing proportion of legumes in the crop rotation, the risk of serious pathogen problems increases. Generally, the maximum proportion of legumes in crop rotation is around 60 %. Model D is based on this hypothetical maximum legume area. In addition, the amount of FYM is increased by 20 % using purchased fodder. Farm D has a slightly higher circulation factor and PPB than farm I, and the total yield is also slightly higher. Since the final products of these two farms are not equal, the comparison is misleading.

Model C is based on a minimum legume area, since legume crops are not cash crops at all. Hypothetically, a slightly lower N intensity on non-legumes could be possible. However, the risk of total crop failure and poor quality of yield in unfavourable weather conditions increases drastically. The poor PPB (0.47) reflects the weakness of the system: no nutrient circulation at all and no direct utilization of legume crops.

Model I is run with the lowest possible N intensity on non-legumes. However, the risk of total crop failure and poor yield quality can be controlled with help of (ruminant)cattle. The circulation factor is lower than in model D because of the 20 % cash crop area. However, legume crops are managed more efficiently resulting in the highest field balance (0.76). In order to produce the given "food basket", this model is superior to the specialized alternative (D+C). According to the present data, this model has close to optimum N utilization. However, other nutrients must be replaced by completing nutrient recycling or from external sources.

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