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Mixing specialized farming systems in Flevoland (The Netherlands): agronomic, environmental and socio-economic effects

J.F.F.P. BOS[1*] AND G.W.J. VAN DE VEN[2]

[1] Animal Production Systems Group, Wageningen Institute of Animal Sciences, Wageningen University, P.O. Box 338, NL-6700 AH Wageningen, The Netherlands
[2] Centre of Environmental Science, Leiden University, P.O. Box 9518, NL-2300 RA Leiden, The Netherlands
[*] Corresponding author (fax: +31-317-485006; e-mail: jules.bos@dps.vh.wau.nl)

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Abstract

Mixed farming systems have potential agronomic, environmental and socio-economic advantages over specialized farming systems. This paper attempts to quantify these advantages for the Dutch province Flevoland. A mixed farming system at regional level is characterized by intensive co-operation between two or more specialized farms, each producing crop or animal products. To test the hypothesis that such a mixed farming system might improve sustainability of agriculture in Flevoland, nutrient balances, labour requirements and labour income were quantified for a specialized arable farm, a specialized dairy farm and both combined into a mixed farming system, exchanging land, labour and machinery. Scope for reduced biocide use in the mixed farming system was assessed in a qualitative way. In the mixed farming system labour income per ha was 25% higher. Seventy percent of this increase could be explained through higher yields per ha of the profitable crops ware potato (*Solanum tuberosum* L.) and sugar beet (*Beta vulgaris* L.). The remaining 30% resulted from lower costs, mainly through a better utilization of available labour. Differences between the combined nutrient balance of both specialized farms and that of the mixed farming system were small. Indications of reduced biocide use in the mixed farming system could not be found. It was concluded that in a mixed farming system it is possible to realize a higher income without increasing environmental pollution. Key factor is the ratio between animal and arable production, determining the extent to which crop rotations can be widened and the relative amounts of slurry that can be applied to grassland.

Keywords: farming systems modelling, interdisciplinary analysis, sustainability, nutrient use efficiency, farm economics

Introduction

A farm system can be defined as a decision-making unit comprising the farm household and/or cropping and livestock systems, that transforms land, capital and labour into useful products that can be consumed or sold (Fresco & Westphal, 1988). The term farming system is used to refer to a class of similarly structured farm systems. Based on Steinfeld & Mäki-Hokkonen (1995), a mixed farming system is defined as a farming system comprising at least one cropping system and one livestock system, in which more than 10 percent of the dry matter fed to animals is farm-produced or more than 10 percent of the total value of production comes from non-livestock farming activities.

Farming systems are subject to two opposite forces: differentiating forces and integrating forces (Schmitt, 1985; Van Niejenhuis & Renkema, 1996). Differentiating forces lead to specialization, leaving few or only one cropping or livestock system(s) at the farm. Differentiating forces represent the requirements that crops and animals place on their physical environment, local price ratios between products and production factors, the skills and preferences of the farmer, and cost savings related to large-scale production. Integrating forces lead to farming systems, in which several cropping and/or livestock systems are combined. Integrating forces are the need to maintain soil fertility, balance labour requirements of crops and/or animals with available labour, balance feed rations of animals, spread financial and plant/animal health risks, and costs of trading and transporting intermediate products. The impact of both opposite forces has led to mixed farms in the past, but since the 1950s, through the application of labour-saving technologies with high fixed costs (mechanization, housing systems), differentiating forces have become dominant, leading to rapid specialization in Dutch agriculture. However, in the past decade a new integrating force has become prominent (Van Niejenhuis & Renkema, 1996): the need to enhance sustainability. A way to achieve this could be re-introduction of mixed farming systems, which compared with specialized farming systems, may result in (Lantinga & Rabbinge, 1996):

- higher nutrient use efficiency (i.e. the proportion of imported nutrients exported from the farming system in farm products);
- reduction in the use of external inputs (fertilizers, biocides, concentrates);
- better utilization of available labour.

Most important mechanisms underlying these expected benefits are use of on-farm produced concentrates, more efficient use of animal manure and wider crop rotations, including grass and fodder crops.

Mixed farming systems at farm level, i.e. all farms producing both animal and arable products, have disadvantages: they are more difficult to manage, require higher investments (Aarts, 1992) and provide fewer opportunities to take advantage of large-scale production. However, mixed farming systems can exist at different organizational levels. At regional level, a mixed farming system comprises at least two specialized farms, each producing crop or animal products in which decisions are made, taking into account goals and constraints of both farms. In mixed farming systems at regional level, the economic benefits of specialization at farm level and environmental benefits of integrating cropping and livestock systems at regional level are combined (Van Niejenhuis & Renkema, 1996). Therefore, they deserve further attention. The aim of this paper is to compare agronomic, environmental and socio-economic characteristics of two specialized farming systems with those of one mixed farming system at regional level.

In this study, the two specialized farming systems are a specialized arable farm and a specialized dairy farm. The extent to which these specialized farms increase their integration may vary, ranging from the exchange of labour and machinery only, to merging both specialized farms into one new mixed farm, adapting the farm plan (crop areas, animal numbers, buildings and machinery) to the newly created situation. De Koeijer *et al.* (1995), in a study at farm level, quantified effects of merging a specialized arable and a specialized dairy farm. Optimizing the farm plan of their mixed farm, resulted in a shift in land use towards more profitable crops at the expense of feed crops. In this study, at regional level, we do not allow changes of the farm plan of the mixed system, to guarantee that only effects of mixing specialized farming systems are quantified and not effects of, for example, shifts in land use. Thus, in this paper the mixed farming system is defined by the specialised arable and the specialised dairy farm, intensively co-operating, exchanging land, labour and machinery. Our key question is: What are the agronomic, environmental and socio-economic effects of re-organizing a specialized arable farm and a specialized dairy farm towards more integration, fixing crop areas and animal numbers, and using the same quantities of land and capital? Formulated in another way, we try to quantify the extent to which the utilization of already present human (labour), capital (machines) and natural (nutrients, soil fertility) resources can be improved through mixing specialized farming systems, without changing crop areas and animal numbers.

Methodology

General

Nutrient input/output ratios and scope for reducing biocide use without yield losses are selected as indicators for natural resource use efficiency. Farm-labour utilization serves as an indicator for utilization of human resources. Since effects of changes in utilization of labour, capital and natural resources are integrated in the generated labour income, this is selected as an overall indicator for economic efficiency. Values of these indicators are quantified for all three farming systems.

In this study many data are fixed (crop areas, machinery, animal numbers). Therefore, relatively straightforward spreadsheet calculations sufficed to answer the questions raised. These are based on a normative approach, departing from well-managed and efficiently organised farming systems. Specific year effects, for example through weather influences, were avoided by using multi-year averages for crop yields and animal production. Trends in these averages were not taken into account. Data used apply to the physical environment in southern and eastern Flevoland. The soil is a calcareous marine loam soil (clay fraction 25–35%, pH-KCl 7.3–7.6, organic matter content 3–6%), reclaimed from the sea 40 years ago. During the growing period, depth of the groundwater table is around 1.5 m.

To assess the impact of mixing specialized farming systems on nutrient use efficiency, a nutrient balance approach was applied, considering nitrogen (N) and phosphorus (P), the two most problematic elements from an environmental point of view. All inputs were quantified, and only those outputs leaving the farm gate in useful products. The difference between total inputs and outputs in useful products is either lost to the environment or stored in soil reserves.

Labour requirements were calculated for each half-month period of the year for each of the farming systems, using normative task times (Anonymous, 1994a; Anonymous, 1995a). Annual labour availability amounts to 2093 hours per full-time labourer on the arable farm and 2349 hours per full-time labourer on the dairy farm. A maximum labour availability per period was assigned to each half-month period of the year according to De Koeijer & Wossink (1992) for the arable farm and according to Van Mensvoort (1993) for the dairy farm. For the mixed farming system, labour availability's and labour requirements per period per farm were added. By confronting labour requirements and labour availability per period, the need for hiring labour was assessed.

Labour income was calculated as revenues minus fixed costs (buildings, machinery, land) and variable costs (costs of external inputs, contract labour, hired labour, etc.) for all three farming systems. Data to calculate revenues and fixed and variable costs were taken from Anonymous (1994a) and Anonymous (1995a).

Scope for reduced herbicide use in the mixed farming system was assessed by comparing crop rotations in the specialized farming systems and the mixed farming system with respect to weed-suppressing capacity. Scope for reduced pesticide use was assessed by examining (1) against which pests and diseases pesticides are applied in the specialized farming systems, and (2) whether the occurrence of these pests and diseases will be reduced in the mixed farming system.

Currently, mixed farming systems hardly exist in the Netherlands, which makes this study future-oriented. Hence, comparing specialized and mixed farming systems is only meaningful when considering specialized farming systems that can be expected to remain economically viable in the coming decade. Farm size is an important indicator of viability. The size of farms most recently issued by the government served as a criterion to separate farms with good future perspectives from those with less favourable perspectives. For arable farms this size was 65 ha, and for dairy farms 55 ha. The definitions of the three farming systems are given below. Important characteristics of both specialized farming systems are summarized in Table 1, and for the mixed farming system in Table 2.

Definition of the specialized arable farm

The Dutch Central Bureau of Statistics (CBS) provided data on crop areas on specialized arable farms >65 ha in southern and eastern Flevoland. Based on these data, a representative arable farm, with typical farm size and crop areas, was defined. The number of arable farms in the years 1995 and 1996 larger than 65 ha amounted to 111, with an average size of 80 ha. The following crop rotation was adopted: sugar beets (25%) – winter wheat (*Triticum aestivum* L.) (25%) – seed onions (*Allium cepa* L.) (12.5%) and grass seed (12.5%) – ware potatoes (25%).

Nutrient balances were calculated using a target-oriented approach. First, total nutrient removal in crop products was calculated. Subsequently, the required nutrient inputs were calculated to realize this nutrient removal.

Crop yields were determined using 5-year averages as given in Anonymous (1994a). Standard N and P concentrations in marketable crop products were taken from Stouthart & Leferink (1992). Multiplying nutrient concentrations by crop yields resulted in nutrient removal in marketable crop products, from which total aboveground N-uptake was derived by dividing this by crop-specific N-harvest-indices, as given by Schröder *et al.* (1993). Based on data given by Schröder *et al.* (1993), Habekotté (1994) calculated crop-specific efficiencies with which crops utilize soil mineral N (defined as total aboveground N-uptake divided by available N) for situations with ample available N. These efficiencies were used to assess the required amounts of mineral N for the five crops in the rotation. P-requirements of the whole crop rotation were met using pig slurry. The P status of the soil was considered 'sufficient' in agricultural terms (Van Der Paauw, 1973). Annual P-input with pig slurry should equal P-removal in crop products from the whole rotation plus 9 kg P ha^{-1} yr^{-1}, the P-surplus allowed by the Dutch government (Anonymous, 1995b). To prevent soil structure damage, slurry at arable farms is applied in late summer, after early-harvested crops, i.e. winter wheat, grass seed, seed onions and ware potatoes. Application of pig slurry is followed by a catch crop (Italian ryegrass, *Lolium multiflorum* Lamk.).

Total available N is the sum of soil mineral N in spring, mineral N originating from decomposition of soil organic matter during the growing season, N from crop residues, N in pig slurry and, if required to meet crop demands, N in artificial fertilizer. Soil mineral N in spring was derived from unfertilized objects in a number of maize N-fertilizer trials on clay soils (Schröder, 1985; Van Der Schans *et al.*, 1995; Van Dijk, 1996) and amounted to 64 kg ha^{-1}. Net mineralization during the growing season is assumed to amount to 100 kg ha^{-1}. Carry-over of nitrogen via crop residues to following crops occurs after sugar beets (30 kg ha^{-1} via beet leaves) and grass seed (30 kg ha^{-1} via stubble and roots). After application of pig slurry in late summer combined with a catch crop, 35% of total N applied with slurry is assumed to be available for the next main crop (Schröder *et al.*, 1996). The remainder is assumed to be either emitted to the environment, or stored in soil reserves.

Based on calculated labour requirements, it is assumed that one full-time labourer is present on the arable farm. Contract labour is used for sowing and harvesting sugar beets and grass seed, sowing onions, harvesting wheat and applying organic manure. The machine inventory on the arable farm is based on Wossink (1993).

Definition of the specialized dairy farm

CBS provided data on crop areas and numbers of animals present on specialized dairy farms >55 ha in southern and eastern Flevoland in the years 1995 and 1996. The Dutch Cattle Syndicate provided data on average annual milk production per cow in Flevoland. These data formed the basis for the definition of a representative dairy farm, with typical farm size, crop areas, number of cows and milk production per ha. The number of dairy farms in southern and eastern Flevoland in the years 1995 and 1996 larger than 55 ha was 36, with an average size of 72 ha. Of the total area used by these farms, 75% was used as grassland, 17% for maize (*Zea mays* L.) and 8% for arable crops. It is assumed here that on all land not used as grassland, maize is grown, i.e. 20 ha. Maize rotates with 40 ha of the grassland area, leaving 12 ha permanent grassland. Each year, 10 ha of ley is ploughed up, followed by maize for two successive years.

Grass dry matter yield was determined using empirical relationships between (i) N-availability and N-uptake and (ii) N-uptake and dry matter yield (Middelkoop & Aarts, 1991). The N-application rate on grassland was set to the economic optimum of 400 kg ha^{-1} yr^{-1} (Prins, 1983). Farm-produced cattle slurry was evenly distributed over the total grassland area and applied in three doses, the last one after the second cut. The N-fertilizer value of slurry was calculated using working coefficients as given by Anonymous (1994b). To arrive at an N-application rate of 400 kg N ha^{-1} yr^{-1}, additional artificial fertilizer was applied.

Herbage quality, animal energy requirements and feed intake by the animals were

Table 1. Characteristics of the specialized farming systems.

Arable farm (80 ha, 1 full-time labourer)			Dairy farm (72 ha, 2 full-time labourers)		
Crop areas (ha) and marketable yields per ha (tons)			*Crop areas (ha) and dry matter yields per ha (tons)*		
sugar beets	20	74.7	permanent grassland	12	12.7
winter wheat	20	8.5	leys	40	12.7
onions	10	57.1	maize	20	13.6
grass seed	10	1.4			
ware potatoes	20	53.9	*Animal data*		
			dairy cows		143
Crop rotation			yearlings		51
sugar beets → winter wheat → seed onion			calves		53
and grass seed → ware potatoes			animal density (cows ha^{-1})		2.75
			concentrates (kg cow^{-1} yr^{-1})		1493
Timing of manure application			*Milk production data*		
application of pig slurry and catch crop in			milk production per cow (kg FPCM yr^{-1})*		8233
late summer after early-harvested crops			milk production per ha (kg FPCM yr^{-1})		16352
			Timing of manure application		
			application of cattle slurry on grassland in		
			growing season		
Activities carried out with contract labour			*Activities carried out with contract labour*		
sowing and harvest of sugar beets			cultivation of maize		
sowing and harvest of grass seed			soil cultivation		
sowing of onions			resowing grassland		
harvest of wheat			application of slurry		
application of slurry			maintenance of ditches		

* FPCM = fat and protein corrected milk

calculated using routines from a dairy farming model (Van De Ven, 1996). Dairy cows graze only during the day. During the night 4.5 kg of dry matter of maize silage is fed indoors. Concentrates are fed only if necessary to meet energy and protein requirements. Feed rations in winter are based on grass and maize silage. By confronting total feed intake of the animal stock with on-farm roughage production, the need for purchased roughage was assessed.

Maize receives artificial fertilizer only. To assess the required dose, the same procedure as described for the crops at the arable farm was followed, however taking into account the nitrogen released in the first and second year after ploughing up grassland. Data on these amounts are scarce, especially for marine loam soils, after temporary grassland and for second and later years after ploughing. Here it was assumed that annual effective nitrogen accumulation under grassland amounts to 100 kg ha^{-1}. After ploughing up grassland, 40% of the nitrogen accumulated during the grassland period becomes available in the 1^{st} year and 20% in the 2^{nd} year (Biewinga *et al.*, 1992). The age of grassland ploughed up is 4 years, thus having accumulated 400 kg N ha^{-1}, 160 kg of which will become available for the 1^{st} year maize crop (similar to the amount obtained by Spiertz & Sibma, 1986) and 80 kg for the 2^{nd} year maize crop.

Based on calculated labour requirements, it is assumed that two full-time labourers are present on the dairy farm. Contract labour is used for manure application, all operations associated with the cultivation of maize (including sowing, spraying and harvesting), maintenance of ditches, resowing grassland and all soil cultivation practices.

Definition of the mixed farming system

As stated, mechanisms underlying the expected benefits of mixed farming systems are use of on-farm produced concentrates, more efficient use of animal manure and wider crop rotations. Using on-farm produced concentrates is, however, not considered in this paper, because it would imply different crop areas. Moreover, in a regional perspective, growing more fodder crops at the expense of arable crops and replacing imported feed ingredients, would not necessarily result in an improved nutrient balance of the farming system, as lower inputs with feed ingredients would largely be offset by reduced outputs in arable products.

A wider crop rotation was established by incorporating the total maize area and the maximum grassland area of the dairy farm into the crop rotation of the arable farm. As on the specialized dairy farm, 12 ha is permanent grassland. Consequently, 40 ha of grassland can be incorporated into the rotation as ley. Ley is ploughed up in November after the fourth summer. Each year 10 ha of ley is sown after an early-harvested crop and 10 ha is ploughed up. The following crop rotation was adopted: onions (10 ha) – ley (1–4 years old, 4*10 ha) – ware potatoes (10 ha) – winter wheat (10 ha) – sugar beets (10 ha) – maize (10 ha) – ware potatoes (10 ha) – grass seed (10 ha) – winter wheat (10 ha) – maize (10 ha) – sugar beets (10 ha). To quantify the amounts of nitrogen available for crops in the rotation from decaying grass roots and stubble, the same rules of thumb as for the specialized dairy farm were applied.

However, for the specialized dairy farm data were only given for the first two years after ploughing up grassland, whereas for the mixed farming system data for subsequent years are also required. Hence, it was assumed that 15% of the accumulated effective nitrogen becomes available in the 3rd year, 10% in the 4th year and 5% in each of the next three years (Biewinga *et al.*, 1992). As on the specialized dairy farm, 4-year old grassland has accumulated 400 kg N ha^{-1}, 160 kg of which will become available for the crop in the 1st year after ploughing, 80 kg in the 2nd year, 60 kg in the 3rd , 40 kg in the 4th and 20 kg in the 5th to 7th years.

As on the specialized arable farm, P-requirements of the whole crop rotation were met using slurry, however, cattle slurry being added to the pig slurry. On the specialized arable farm, slurry had to be applied in late summer, associated with a low N utilization efficiency. In the mixed farming system, part of this slurry can be applied to grassland in the growing season. Application of slurry in late summer can thus be avoided by maximizing slurry application on grassland. This slurry application strategy aims at accumulating P in the soil profile under grassland in rotation, such that P-requirements of crops grown after ploughing up grassland are met as much as possible. The maximum dose per cut was set to 30 m^3 of slurry, while per year a maximum of three doses can be applied, the last dose after the second cut. The N-fertilizer value of slurry was calculated in the same way as for the specialized dairy farm.

The cropping frequency of crops grown in the specialized farming systems is

Table 2. Characteristics of the mixed farming system.

Mixed farming system (152 ha, 3 full-time labourers)				
Crop areas (ha) and yields per ha (tons)			*Animal data*	
sugar beets	20	85.4	dairy cows	143
winter wheat	20	8.5	yearlings	51
onions	10	57.1	calves	53
grass seed	10	1.4	animal density (cows ha^{-1} grassl. + fodder crops)	2.75
ware potatoes	20	61.9	concentrates (kg cow^{-1} yr^{-1})	1493
permanent grassland	12	12.7		
leys	40	12.7	*Milk production data*	
maize	20	14.8	milk production per cow (kg FPCM yr^{-1})	8233
			milk production per ha grassl. + fodder crops (kg FPCM yr^{-1})	16352
Crop rotation onions (10 ha) → ley (4*10 ha; 1-4 years old) → ware potatoes (10 ha) → winter wheat (10 ha) → sugar beets (10 ha) → maize (10 ha) → ware potatoes (10 ha) → grass seed (10 ha) → winter wheat (10 ha) → maize (10 ha) → sugar beets (10 ha)			*Activities carried out with contract labour* sowing and harvest of sugar beets, grass seed and maize sowing of onions harvest of winter wheat application of slurry maintenance of ditches	
Timing of manure application maximum application of slurry on ley in growing season, remainder with catch crop after early-harvested crops				

Table 3. Yield reduction factors as a function of cropping frequency (Habekotté, 1994). Yield reduction factors applicable to the specialized farming systems are printed bold.

	Cropping frequency						
	1:1	1:2	1:3	1:4	1:5	1:6	>1:7
Sugar beets	0.48	0.37	0.26	**0.13**	0.05	0.0	0.0
Ware potatoes	0.25	0.15	0.15	**0.13**	0.09	0.04	0.0
Maize	0.13	0.10	**0.08**	0.06	0.03	0.0	0.0

higher than in the mixed farming system, which for some crops in the specialized farming systems results in yield reductions, due to soil-borne pests and diseases. Based on Dutch long-term crop rotation experiments, Habekotté (1994) derived yield reduction factors as a function of cropping frequency for a number of crops (Table 3, with bold-printed numbers applying to the specialized farming systems). Because of reduced cropping frequencies, yield reduction factors are absent in the mixed farming system. It is assumed that the higher-yielding crops in the mixed farming system have the same nutrient concentrations as in the specialized farming systems and that nutrients are taken up with the same (crop-specific) efficiencies.

In the mixed farming system, machinery of both specialized farms is combined. As a result, the mixed farming system is less dependent on contract labour. Hence, spraying of maize, resowing grassland and all soil cultivation practices that were carried out in contract labour on the specialized dairy farm, can be carried out with own machinery in the mixed system, provided available labour is not yet fully utilized. Contract labour is still used for sowing and harvest of sugar beets, grass seed and maize, sowing onions, harvest of winter wheat, manure application and maintenance of ditches, because the machinery for these activities is lacking on both specialized farms.

Results

Nutrient balances

Nutrient balances of the specialized farming systems and the mixed farming system are given in Table 4. Differences between the combined nutrient balance of both specialized farming systems and that of the mixed farming system are small. Nutrient output is somewhat higher in the mixed farming system, because of higher yields of sugar beets and ware potatoes. As crop nutrient requirements were calculated using a target-oriented approach and it was assumed that the higher-yielding crops in the mixed system take up nutrients with the same efficiency as in the specialized farming system, a higher nutrient output with crops in the mixed system requires higher inputs. Accordingly, P-requirements of the crop rotation in the mixed system are somewhat higher, explaining the higher pig slurry input. Because in the mixed farming system part of the pig slurry can be applied to grassland in the growing season, N in pig slurry is utilized more efficiently than in the specialized system, and a reduction in artificial fertilizer input was to be expected. However, even despite the higher N release in the mixed system after ploughing up grassland (400 kg N ha^{-1} grassland ploughed up *vs.* 240 kg at the specialized dairy farm), this is not the case: N input with artificial fertilizer is higher. This is related to the fact that the amount of pig slurry that could be applied to grassland is limited to 15% of all pig slurry applied (while the remainder still had to be applied in late summer), and to higher crop N requirements of sugar beets, ware potatoes and maize. As a result, differences in utilization of N in pig slurry are small: per kg N applied in pig slurry in the specialized farming systems, i.e. the arable farm, 0.35 kg N is effective, whereas in the mixed farming system each kg of N in pig slurry results in 0.38 kg effective N. Roughage input is lower in the mixed farming system because of a higher maize yield, reducing the need to purchase maize. Inputs with concentrates, deposition and sundries do not differ between the systems, because it was assumed that these inputs were not affected by mixing specialized farming systems.

In the mixed farming system, the amount of pig and cattle slurry applied is tuned to the total P-removal in products. Within the specialized farming systems this holds only for the arable farm, whereas at the specialized dairy farm all slurry produced by the livestock is evenly distributed over the grassland area, neglecting P accumulation.

Labour requirements

In Table 5, for all three farming systems an overview is presented of annual labour availability, on-farm labour input, required hired labour, total labour requirements and labour surplus (calculated as available labour minus on-farm labour input). It

Table 4. Nutrient balances of the specialized farming systems and the mixed farming system. All data are expressed in kg ha^{-1} yr^{-1}.

	Arable farm (80 ha)		Dairy farm (72 ha)		Total specialized (152 ha) (152 ha)		Mixed	
	N	P	N	P	N	P	N	P
Inputs								
pig slurry	147	37	0	0	78	20	81	21
art. fertilizer	89	0	161	1	123	0	126	0
roughage	0	0	46	7	22	3	20	3
concentrates	0	0	97	24	46	12	46	12
deposition	34	0	34	0	34	0	34	0
sundries	0	0	7	1	3	0	3	0
total inputs	270	37	345	33	306	35	310	35
Outputs								
crop products	145	29	0	0	77	15	82	16
milk/meat	0	0	102	19	48	9	48	9
total outputs	145	29	102	19	125	24	131	25
surplus	125	8	243	14	181	11	179	10
outputs/inputs	0.54	0.78	0.30	0.58	0.41	0.69	0.42	0.71

Table 5. Labour requirements and supply in the specialized farming systems and the mixed farming system. All data expressed in h yr^{-1}.

	Arable farm	Dairy farm	Total specialized	Mixed
Labour availability farmer(s)	2093	4698	6791	6791
On-farm labour input	1987	4424	6411	6585
Hired labour input (excl. contract labour)	652	316	968	851
Total labour requirements	2639	4740	7379	7436
Labour surplus	106	274	380	206

shows that annually hired labour is 12% lower in the mixed farming system. This is due to the fact that if, for example, at the specialized dairy farm a labour shortage exists in period March-1, this can not be covered by a possible labour surplus from the specialized arable farm, and additional labour has to be hired. In a mixed farming system context, where at the dairy farm part the same labour shortage occurs in March-1, it is indeed possible to use labour from the arable farm part. On an annual basis, this results in a reduction of 117 hours of hired labour.

The same mechanism also causes higher labour requirements in the mixed farming system: where in the specialized farming systems in a certain period contract labour is used, in the mixed farming system contract labour may be substituted by labour still available at the dairy farm part or the arable farm part, provided the required machinery is present. Consequently, cultivation and ploughing of the maize stubble, seedbed preparation for leys to be established and ploughing up of grassland can in the mixed farming system be carried out with own labour and machinery, where in the specialized farming systems these activities are carried out using contract labour.

Because of the higher on-farm labour input in the mixed farming system, the labour surplus is lower, or, in other words, available labour is used more efficiently.

Labour income

Labour income in the mixed farming system is about Dfl 500,– ha^{-1} higher than that in the specialized systems (Table 6). This higher labour income results mainly from higher revenues, making up 70% of the increase in labour income, rather than from lower costs. Higher revenues in the mixed farming system result from higher yields per ha of the profitable crops sugar beets and ware potatoes. Lower costs mainly originate from a more efficient utilization of available labour, reducing contract labour costs (explaining 16% of the increase in labour income) and lower variable costs (explaining 10% and mainly originating from a reduced need to purchase maize).

Biocides

In general, mown crops have a higher weed-suppressing capacity than root crops, mainly because their soil cover is higher. Especially the weed-suppressing capacity of grassland is high, because it is a very dense, multi-annual crop and regularly

Table 6. Costs, revenues and labour income in the specialized farming systems and the mixed farming system. All data are in Dfl ha^{-1} yr^{-1}.

	Arable farm	Dairy farm	Total specialized	Mixed
Fixed costs	3249	6049	4575	4575
Variable costscosts contract labour	538	987	751	669
costs hired labour	223	120	174	154
other variable costs	1986	3124	2525	2472
Total costs	5996	10281	8026	7870
Revenues	7393	13212	10149	10509
Labour income	1397	2931	2124	2639

grazed or mown, preventing annual weeds to produce seed and depleting perennial weeds. Weeds can thus be suppressed by alternating crops with low weed-suppressing capacity with those with high weed-suppressing capacity (Vereijken *et al.*, 1994). As the share of mown crops in the rotation of the mixed farming system is higher than in the specialized arable farming system, in the longer term weed incidence in arable crops may be lower, reducing the need to apply herbicides. Empirical data supporting this are, however, lacking. For instance, Van Dijk *et al.* (1996) monitored weed incidence in several grass – maize rotations on sandy soils, varying in length of the grassland period (0, 2 and 6 years). The rotations showed no differences with respect to emergence of weeds in maize after ploughing up grassland. Most important weeds that germinated were annual *Chenopodium* species. This was explained by the absence of stimulation of seed germination through soil cultivation in grassland, leaving the seed bank intact, and by the fact that seeds under an undisturbed grass sward remain viable for many years. In another long-term experiment, weed incidence was monitored in several rotations, with different shares of root crops. No differences among rotations were found with respect to the occurrence of annual weeds, but perennial dicotyledonous weeds tended to be more prominent in crop rotations with a high (>67%) share of dicotyledonous crops, irrespective of the ratio between mown and root crops in the rotation (Hoekstra & Lamers, 1993). Schotveld & Kloen (1996) studied weed incidence on 10 arable organic farms with rotations in which root crops alternate mown crops. They found that populations of perennial and particularly annual weeds increased in both mown and root crops. Thus, alternating root crops and mown crops in a rotation does not necessarily result in reduced weed populations.

In conclusion, although in theory reduced weed incidence in the mixed farming system is expected, empirical data do not allow a quantitative assessment of the possible reduction in herbicide use.

The pesticides used in the specialized farming systems are all applied to control non-soil-borne pests and diseases like beetles, flies, aphids, thrips, mildew, leaf rust, yellow rust, leaf spot and wire worms and for haulm killing (Anonymous, 1994a; Anonymous, 1995a). Consequently, widening of crop rotations is not likely to influence the need to apply these pesticides.

Discussion

In this paper, agronomic, environmental and socio-economic effects of mixing a specialized dairy farm and a specialized dairy farm have been quantified. Calculations are based on a normative approach and should be considered as such. Under the assumptions made, the main agronomic effect of mixing is higher yields per ha of ware potatoes, sugar beets and maize. The main socio-economic effect is a 25% higher labour income per ha. Seventy percent of this increase is achieved through higher yields per ha of the profitable crops ware potatoes and sugar beets. The remaining 30% is the result of lower costs, due to a more efficient utilization of available labour, reducing contract labour and hired labour costs and due to lower costs for purchasing maize. Environmental effects are limited. Differences between the combined nutrient balance of both specialized farming systems and that of the mixed farming system are small. Improved N use efficiency was to be expected in the mixed farming system, because pig slurry could be applied to grassland in the growing season, instead of in late summer. However, due to the ratio between grassland and arable crops and due to the relatively high cattle slurry production per ha of grass (related to the intensity of the dairy farm), the proportion of pig slurry that could be applied to grassland was limited to only 15%. Consequently, N use efficiency was hardly improved. Mixing specialized farming systems in Flevoland has no effect on the need to apply biocides.

The overall conclusion is that a 25% higher labour income per ha can be attained without increasing environmental pollution as indicated by N and P surplus and biocide input.

De Koeijer *et al.* (1995), using linear programming, maximized labour income for a specialized dairy farm, a specialized arable farm and the merger of both farms, i.e. a mixed farm. At their mixed farm, labour income per ha was 63% higher than the sum of that generated on both specialized farms. In this paper, the increase in labour income per ha at the mixed farm amounted 'only' to 25%. The major reason for the much higher increase at their mixed farm was a shift in land use towards more profitable crops at the expense of feed crops. Such a strategy is opportune at farm level, but not necessarily at regional or higher levels: if all farmers applied this strategy, prices of the more profitable crops would decrease and those of forage crops rise.

Contrary to the results in this paper and those of De Koeijer *et al.* (1995), Oskam (1996) concluded on the basis of an extensive statistical data analysis, that specialized dairy farms, characterized by a high milk production per ha forage crops, generate more income than less specialized ones, also per unit of N-surplus (i.e. the difference between N-inputs and useful N-outputs). However, since Oskam was comparing two groups of farms varying in intensity of land use, the statistical analysis not necessarily reflects a causal relationship between degree of specialization and economic performance. Moreover, the higher income per unit of N-surplus is likely to be the result of a shift of part of their N-losses to the producers of purchased inputs (Aarts *et al.*, 1989).

Effects of mixing specialized farming systems were quantified starting from two specialized farms, each with a specific size. Starting from other farm sizes will yield different results. Should we have started from a specialized dairy farm half the size, with the same milk production per ha, but only one full-time labourer, the benefits of mixing would have been smaller. Cropping frequencies would have been lowered to a smaller extent, resulting in smaller yield increases of the profitable crops. Moreover, opportunities to apply pig slurry to grassland in the growing season would have been even more limited. No differences would occur with respect to utilization of available labour: not only labour availability decreases, but also and to the same extent labour requirements. Finally, the increase in labour income would have been smaller, due to the smaller increases in yield per ha of profitable crops.

The opposite situation would occur when starting from a specialized arable farm half the size, but still with one full-time labourer. In that case the major part of the pig slurry can be applied to grassland in the growing season, resulting in higher N use efficiency. Cropping frequencies of the arable crops would be lowered to an even larger extent, however not resulting in higher yields per ha, as yield reduction factors were already absent in the defined mixed farming system. Starting from a smaller arable farm would imply that more contract labour can be substituted by own labour. However, its cost-reducing effect would be limited, as in the defined mixed system the majority of contract labour costs is for activities for which the required machinery is lacking on both farms.

In this paper it is shown that in a mixed farming system it is possible to realize a higher income and reach higher production levels without increasing environmental pollution. These results raise the question to what extent farmers currently co-operate with neighbouring farms in a comparable way as in this paper. Although different forms of co-operation between farmers are not at all uncommon, quantitative data regarding this are not known to us. Whether farmers are inclined to co-operate intensively with other farmers, will be determined by their willingness to sacrifice part of their independence and accept the complexity of the arrangements needed to organize such increased co-operation. Furthermore, perspectives for mixed farming systems at regional level are determined by the future balance between integrating and differentiating forces. As stated earlier, a new integrating force is the need to enhance sustainability. While environmental advantages of the mixed farming system as defined in this paper were limited, drawing general conclusions regarding environmental aspects of mixing specialized farming systems is not yet possible, because we considered only two specific specialized farming systems. Key factor is the ratio between animal and arable production in the region, determining the extent to which crop rotations can be widened and the relative amounts of slurry that can be applied to grassland. Moreover, numerous other ways of mixing specialized farming systems are possible, e.g. involving other crops, animals and management options. Systematic model analysis, combining quantification of agro-ecological, environmental and socio-economic indicators for a wide range of production techniques and optimization, seems a promising approach to the exploration and design of mixed farming systems.

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