

Dairy production systems in Finland

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Abstract

In Finland milk and beef contribute 50% of the agricultural gross return. The growing season is short, 125-180 days, and therefore the indoor period plays a major role relative to the grazing season. This leads to high capital costs for production (winter-proof housing systems, forage and slurry storage, harvesting machinery). Thus, production demand per animal is high and Finnish cows produce ca. 8,000 kg energy corrected milk per cow per year. Milk production is mostly located in central and northern parts of Finland where climate and geology restrict other agricultural land use options. Finnish dairy farms and herds have been small, but there has been a continuous increase in herd size, currently averaging 33 cows per herd. Grass silage contributes 55-60% of the dietary dry matter. Hard winter conditions limit the choice of forage species; the most important are timothy, meadow fescue and red clover. Potential annual grass yield is 9-12 Mg ha⁻¹, typically harvested 2 or 3 times per season. Silage is mostly pre-wilted and additives are commonly used. Concentrates typically include barley, oats and rapeseed meal. Grassland covers 32% of the agricultural land and therefore the forage production practices have strong environmental impacts.

Keywords: milk production, grassland, cattle, farm economy, animal welfare, dairy cow

Introduction

Milk production is the most important agricultural sector in Finland. It is based on family-owned farms that are small in area but managed at high intensity. All the production systems are based on highly digestible grass silage supplemented with relatively high amounts of concentrate feeds. The short summer season leads to a long indoor period with high demand for conserved feeds and production of large amounts of slurry. Requirements for infrastructure (cow house, silage and slurry storages) and machinery are high, causing large costs for production. The administrative demand for slurry storage capacity is one year.

There are two different dairy production systems in Finland: farms are either managed conventionally or organically, but the latter contribute only 2.5% of Finnish milk production. Further differences among systems are mostly due to the level on production intensity.

In this paper we will describe dairy systems generally and the reasons behind its evolution. We start with effects of geology and climate that form the physical basis of production. We continue by describing the cows and their welfare issues, typical diets, forage production, environmental issues and farm economy, and finally ending with a consideration of the most important future challenges.

Geography, climate and land use

The topography in Finland is relatively flat and the soils are naturally acidic (Peltovuori, 2006; Soil Atlas of Europe, 2005). Finnish soils are young and weakly developed because of the effects of the last glacial period, which ended ca. 10,000 year ago. During the melting of ice, clay soils formed on the low-lying coastland areas, resulting in large and uniform fertile cambisols (WBR classification). Inland,

the agricultural soils are typically formed of coarser materials (silt, sand) and their existence is more fragmented. Mineral soils are mainly podsoles and organic soils (peat) histosols.

The agricultural area occupies a lower proportion of the total land area (9%) than in most European countries (OFS, 2015). The area occupied by lakes and water courses is high (10%). These water bodies are poor in nutrients, which makes them vulnerable to nutrient loads from agricultural activities. Cereal farms occupy most of the agricultural land, and their share is increasing. Dairy farms occupy approximately 25% of the agricultural land, and their share is decreasing. Mainly this is due to high labour demand of dairy production compared to the cereal production and the opportunity to get extra income from working outside of the farm.

Almost all Finnish agricultural land is located above latitude 60° N. The climate is under a mixture of continental and maritime influences due to the location between the Eurasian continent and the Atlantic Ocean (Kersalo and Pirinen, 2009). The dairy production area is characterized by a short growing season. The temperature sum is low and the snow cover period is long compared with the main dairy production areas of Europe (Table 1). Snow cover has important consequences: it provides a very effective protection against the effects of low temperatures during winter (Belanger *et al.*, 2002) and provides ample melt-water for the plants in spring (Pulli, 1980). It also affects strongly the surface run off and leaching (Saarijärvi, 2008) and even affects gaseous emissions (Maljanen *et al.*, 2009; Virkajärvi *et al.*, 2010).

The Finnish climate is better suited for grass than cereal production. Perennial grasses and legumes are able to utilize the long days with ample solar radiation, temperature and abundant water supply of the early summer. During midsummer the water deficit may occasionally restrict herbage productivity. In late summer, development slows down due to shorter days, lower solar radiation and falling temperatures as the winter approaches. Together with larger night/day temperature differences, these are environmental signals for perennial forages to prepare for the winter (Pulli, 1980). Night frosts occur frequently, except in July (Kersalo and Pirinen, 2009); this narrows the choice of suitable forage species and may further hamper the growth processes of forages during spring.

Cattle

The most common dairy breed is the Nordic Red, which was previously known as the Finnish Ayrshire but is currently bred as a single population with the red breeds from Sweden and Denmark. The other major breed is the Holstein, and its proportion is slowly increasing. The native Finncattle breed comprises three distinct types and has barely been saved from becoming extinct. The major characteristics of the breeds are presented in Table 2.

Table 1. Climatic comparison: Kuopio and other important dairy production locations in Europe (ECA&D; 2015EEA 2015).

Parameter	Finland Kuopio	Estonia Voru	France Paris	Netherlands De Bilt	Ireland Birr	Denmark Copenhagen	Poland Warsaw
Growing season (d)	160	193	321	302	329	250	231
Annual mean temp (°C)	3.1	6.0	12.1	10.0	9.7	9.2	8.4
Growing ¹ DD °C	1,418	1,833	3,064	2,418	2,168	2,207	2,255
Annual precipitation (mm)	608	648	632	817	828	637	542
Days with snow cover (y ⁻¹)	150	120	30	30	n.a. ²	30	60

¹ DD = degree days, base temperature 0 °C.

² n.a. = not available.

Table 2. Major characteristics of the dairy breeds in Finland. Data from the milk recorded herds in 2013 collected by ProAgria Rural Advisory Services.

Breed	Nordic Red	Holstein	Finncattle (3 types)
Milk production, kg year ⁻¹	8,640	9,520	6,120
Milk protein, g kg ⁻¹	34.1	32.9	34.4
Milk fat, g kg ⁻¹	42.7	39.6	44.2
Milk solids kg year ⁻¹	664	690	481
Live weight, kg	597	645	527
Proportion of all cows, %	59	39.5	1.2

Development of dairy farms and milk production

There has been strong structural change across the whole agricultural sector, including dairy production, during the last decades. The number of dairy farms in Finland peaked in the 1960s, when it was in excess of 300,000 farms with a total of 1.1 million dairy cows, mostly native Finncattle. Since then the average farm size has been increasing both in surface area and in average herd size, reaching 56 ha and 33 cows in 2012. The herd size is still increasing and the largest dairy farms in Finland now have more than 300 cows. During the last ten years the total amount of dairy cows has declined by almost 20% to 284,000 in 2012. However, at the same time the total amount of milk produced has declined by a smaller amount, less than 8%, due to increased average production per cow, which reached almost 8,000 l in 2012 (Table 3). Although in the European context the production intensity per cow is high, the intensity per ha is relatively low. The annual milk production is only 4,350 kg ha⁻¹, whereas in the Netherlands it is 10,000-12,000 kg ha⁻¹ and in Sweden 6,600-6,900 kg ha⁻¹ (Virtanen and Nousiainen, 2005). In addition to climatic factors (short growing season), Finnish dairy production is strictly limited by administration. The whole country is classified as a nitrate vulnerable zone and thus N fertilization of grassland is restricted to 250 kg N ha⁻¹, when biological optimum would be 330-350 kg N ha⁻¹ (Salo *et al.*, 2013).

Simultaneously with the structural changes in farm and herd size, there has been a shift in the geographic location of dairy production within Finland. In the 1960s milk production was relatively evenly distributed throughout the country, but nowadays over half of the dairy cows and milk production is located in central Finland, especially in the North Savo and Ostrobothnia regions (Figure 1). This is partly due to environmental conditions: in the south and west coastal zones there are plenty of choices for production in addition to dairying, but in inland areas the fields are more suitable for forage production than arable cropping.

Table 3. The development of dairy production in Finland from 1980 to 2012 (OFS, 2015).

Year	Number of dairy farms (×1000)	Number of dairy cows (×1000)	Average milk production, l cow ⁻¹	Arable land, ha farm ⁻¹	Dairy cows farm ⁻¹	Dairy cows ha ⁻¹	Total milk production (million litres y ⁻¹)
1980	91.3	719	4,478	n.a. ¹	11.5	n.a.	3,170
1990	45.5	496	5,547	19.3	13.0	0.67	2,730
2000	22.2	364	6,786	32.6	15.2	0.47	2,450
2012	9.6	284	7,876	56.4	33.1	0.59	2,230

¹ n.a. = not available.

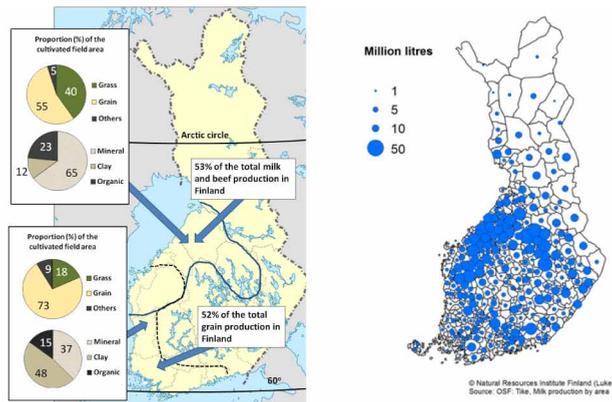


Figure 1. Regional differences in soil properties and crop production in main agricultural area and detailed distribution of milk production in counties in Finland 2013-2014 (OSF, 2015).

In addition, the Finnish subsidy system provides higher subsidies in the northern areas compared to southern areas. Historical reasons have resulted in land ownership becoming fragmented and, because of geographical reasons, agricultural land is distributed in small and often unevenly shaped parcels. The average distance of a hectare from the farm was 2.3 km in 2009 (Niskanen and Heikkilä, 2015). The main milk production regions are the most fragmented in the country. This presents challenges for feed and manure management.

Most of the dairy barns are tie stalls (71%), but as they are on average smaller than loose-housing systems, half of Finnish cows are kept in loose-housing systems. The new investments are most typically based on automatic milking systems (AMS) and have either 60 cows (one AMS unit) or 120 cows (two AMS units). The number of farms with AMS has increased from two in 2000 to 818 (with a total of 1,094 AMS units) in 2013, and the number keeps increasing steadily (65-111 new AMS farms per each year in the years 2008-2013). Today ca. 25% of milk produced in Finland comes from AMS farms (Manninen, 2013, and E. Manninen, personal communication).

Animal health and welfare

The average productive lifetime (4.9 years) of Finnish dairy cows has remained almost unchanged over the last fifteen years. The average replacement rate was 34% in 2010 (Heikkilä, 2013). The list of the main reasons for involuntary culling (50% of all cullings) reflects also the major health issues: mastitis (21%) and fertility (19%) (Heikkilä, 2013). Finland is free from the major infectious cattle diseases, such as enzootic bovine leucosis, brucellosis, bovine tuberculosis, infectious bovine rhinotracheitis, parafilaria, strongylus, trichomoniasis and bovine viral diarrhoea. The prevalence of infections like *Salmonella*, EHEC, trichophytosis, paratuberculosis and *Mycoplasma bovis* is also very low. Regular vaccinations are not needed on cattle farms.

The shift from tie stalls to loose housing can be regarded as a factor promoting animal welfare. On the other hand, the concomitant increase in herd sizes reduces the opportunities to arrange grazing (see below). Both loose housing and grazing opportunity are regarded to be important for the welfare of dairy cows from a behavioural point of view (Welfare Quality 2009). The adoption of technology for monitoring production, health and welfare of cows is tightly connected to the adoption of AMSs, the main extra features being systems for automatic mastitis control and heat detection. Also some farms with traditional milking parlours have acquired automatic heat detection systems.

Feed evaluation system

The feed evaluation system in Finland is maintained by the Natural Resources Institute Finland (Luke). It is presented in a web-based service by Luke (2015). The energy value is based on metabolizable energy (MAFF, 1975) and presented as megajoules. The protein system is based on the amino acids absorbed from the small intestine and protein balance in the rumen (AAT/PBV system) originally developed as a Nordic cooperation (Madsen *et al.*, 1995), but with a number of national modifications. The feeding value of ensiled grass is typically analysed by NIRS in practice. The NIRS method includes all silage quality components: chemical composition, energy, protein and ensiling quality.

The ration formulation for dairy cows in Finland is based on static feed values, but new elements have been taken into use in practical ration formulation through the program CowCompass, which is run by the experts of the ProAgridia Rural Advisory Service. The ration optimization of CowCompass is based on published empirical relationships of feed composition, feed intake (Huhtanen *et al.*, 2007, 2008, 2010), associative effects in digestion (Huhtanen *et al.*, 2009) and milk production responses (Huhtanen and Nousiainen, 2012). Rations can be optimized based on least-cost ration or maximum milk income minus feed cost. Nowadays the milk price is still relatively high compared to feeding costs, which leads to high feeding intensity. High intensity means using high digestibility grass silage simultaneously with large amounts of concentrate supplementation. In many cases the risks of acidosis and hoof disorders become limiting factors in milk production. However, these health factors overrule economic optimization within the program, resulting in reduced diet intensity (usually lower amount of concentrates) compared to the economic optimum.

Feed production

Grass silage and cereals are typically produced on-farm and commercial feeds comprise on average 29% of the total dry matter (DM) consumed by cows (Huhtamäki, 2014). The DM yield of grass is about double that of cereal grains and the digestibility of grass organic matter is high despite of its high neutral detergent fibre content. High grass yield per ha combined with reasonably high digestibility makes grass production an economically profitable way to produce milk in Nordic circumstances, where maize is not an option. The use of high digestibility grass also makes diet rationing relatively easy and safe because cows can compensate for random variation in the concentrate supplementation by adapting their grass silage intake.

The rations are likely to change based on the relative prices of commercial feeds, but the best possible utilization of on-farm produced forages is generally targeted. The feed consumption statistics collected by ProAgridia Rural Advisory Services in 2013 showed that grass silage comprised, on average, 48% of dairy cow DM intake and the proportion of grazed grass was 6%. The concentrate proportion was thus 46%; this amount has slightly increased during recent years (Huhtamäki, 2014). Rapeseed-based protein supplements are commonly used and very little soybean meal is used in dairy cow diets in Finland. The farms aiming at production exceeding 10,000 kg ECM cow⁻¹ y⁻¹ use up to 60% of dietary DM as concentrates in order to achieve this goal. In more extensive production systems, larger proportions of grass silage in the diet are used.

Approximately one third of arable land is used for grass, which is mainly used as feed for dairy cows (Figure 2; OFS, 2015). Due to the short growing season, great emphasis has been put on developing ensiling and knowledge-transfer actions within forage production and preservation in Finland (see e.g. Huhtanen *et al.*, 2012), which have contributed to the generally good nutritional and fermentation quality of Finnish grass silage. Salo *et al.* (2014) reported results based on over 110,000 farm silage samples collected during 1998-2012, showing that the average D-value (digestible organic matter in DM) was 674 g kg⁻¹ DM, DM concentration 321 g kg⁻¹, crude protein concentration 147 g kg⁻¹, pH 4.2 and

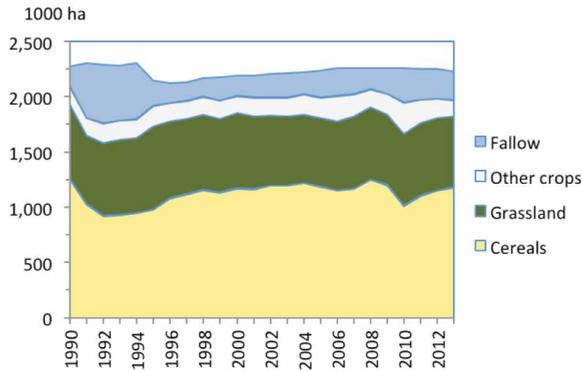


Figure 2. Cultivated area of different arable crops in Finland during years 1990-2013 (OFS, 2015).

ammonium N in total N was 44 g kg⁻¹ N. These numbers demonstrate the high ambitions and abilities of the Finnish forage farmers.

Ensiling technologies develop fast and several methodological options are available depending on the particular circumstances and needs of the farms. On larger dairy farms it is very common to use precision chopping of moderately pre-wilted grass and ensile it into bunker silos using formic acid-based or biological additives. The relatively low inherent water soluble carbohydrate content of the Finnish silage raw material, which is due to the species used and environmental conditions, support the use of silage additives. Round bales are also used.

Grazing contributes approximately 6% of the annual feed DM intake of cows. This low proportion is partly due to the short grazing season and partly due to the lack of suitable grazing paddocks near the dairy barn, and also difficulties in combining grazing with automatic milking systems. The majority (77.6%) of cows still graze during the summer time. Mostly used grazing methods are rotational and strip grazing. Recommended pasture area is low (0.17-0.2 ha cow⁻¹) during early summer and increases to 0.3-0.45 ha cow⁻¹ in later summer when grass growth decreases (Virkejärvi, 2005). Grazing is a compulsory part of the summer feeding regime in organic milk production, but because organic farms comprise only a small proportion of total farms it has only a minor impact in terms of overall grazing intensity.

Forage species and management

Permanent grassland in Finland occupies only 4% of the grassland area, which is a low proportion compared to most European grasslands (OFS, 2015). Instead, most Finnish silage production is based on rotational ley farming, i.e. the perennial swards are a part of the crop rotation. Based on the Field Parcels Registry (ProAgria Rural Advisory Services), the mean age of leys before new establishment is 4.4 years (Niemiäinen, 2015: personal communication). The main reason for frequent re-establishment of leys is the clear decrease in the productivity of swards over time (Figure 3). This decrease is mainly caused by winter damage, and consequential invasion by weeds that are of low productivity (Nissinen and Hakkola, 1994). The proportion of annual swards is minor. Swards are established typically using cereals as cover crops, or whole crop silage. Larger and more intensive farms are establishing more leys directly after the previous ley (Niemiäinen, 2015: personal communication). One possibility is to improve grassland productivity by reseeding grass (or legume) seed directly into the existing grassland. This technique is more popular among farms that have high animal density per hectare, thereby concentrating on grass farming and purchasing concentrates from outside the farm.

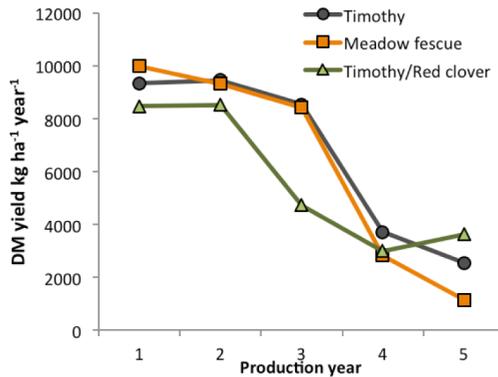


Figure 3. An example of typical dry matter decrease in three species during successive years after establishment (Modified from Nissinen and Hakkola, 1994).

The most important forage species are timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.). These are preferred because of their combination of good winter tolerance, reasonably high yield capacity and high nutritive value under Finnish conditions and management guidelines. They are most commonly used in mixtures. The proportions of seeds used in mixtures vary according to the planned use and soil type. There has also been increasing interest in tall fescue (*F. arundinacea* Schreb.) because of its tolerance of water shortages and good regrowth ability (Virkejärvi *et al.*, 2012). In addition there is much interest in festulolium (*Festuca × Lolium*) cultivars but most currently available cultivars do not tolerate winter conditions sufficiently. Cocksfoot (*Dactylis glomerata* L.) and smooth meadow grass (*Poa pratensis* L.) are much less used. The winter tolerance of perennial ryegrass (*Lolium perenne* L.) is still poor.

Due to the climatic conditions the spring growth of swards is vigorous, reaching 270 kg DM ha⁻¹ d⁻¹ (Virkejärvi *et al.*, 2003). Because of the short summer and long days (up to 20 h daylight in summer solstice in North Savo) there is very little variation in heading date among cultivars of the species. For example there is only 3 days difference in the heading date between earliest and latest timothy cultivars (Kangas *et al.*, 2006). Therefore there is no grouping of cultivars into early or late types. In all, this leads to a relatively narrow time window for optimum harvest in the first cut (Kuoppala, 2010; Rinne and Nykänen, 2000) and consequently, this leads to high investment demand on harvesting machinery. It would be beneficial to find such forage species or cultivars or systems that would increase the time span for harvesting high digestible silage in the first cut. In the following cuts the rate of changes in forage amount and digestibility is clearly slower (Kuoppala, 2010; Pulli, 1980).

Among forage legume species, red clover (*Trifolium pratense* L.) is still the most important (Halling, 2002; Riesinger, 2010) and it is mainly used in seed mixtures with timothy and fescues. White clover is not well suited for inclusion in tall growing (up to 70-80 cm) Finnish silage leys (Virkejärvi and Järvenranta, 2001; Halling, 2002). Its performance under grazing without N fertilizer has been fairly good when compared with N-fertilized grass pasture (Saarijärvi, 2008). However, as pasture comprises a low proportion of the total grassland area, the role of white clover is also minor. The performance of lucerne (*Medicago sativa* L.) has been shown to be clearly lower than that of red clover, mainly because of poor winter tolerance and the low pH of Finnish soils (Halling *et al.*, 2002).

In practice, there is hardly any maize silage production in Finland. In plot experiments the productivity of maize may be up to 20 Mg DM ha⁻¹ but variation in yield level is extremely high (Saarinen *et al.*, 2013).

Nutrient use, fertilization, manure and nutrient balances

Fertilization of N and P are regulated by the Nitrate Directive that is applied across the whole country without exceptions, and by the voluntary Finnish Agri-Environmental Scheme that covers over 90% of Finnish farms. There is a concern that with increasing restrictions in the new scheme (2015-2022) the popularity of voluntary membership in the Agri-Environmental Scheme might diminish, but this remains to be seen. Fertilization guidelines are based on soil analyses of main nutrients, analysed with acidic ammonium acetate (Vuorinen and Mäkitie, 1955). Guidelines for N-fertilization have been based on soil type and cultivation zone, but from 2015 onwards the concentration of soil organic matter will be the basis for this. In addition, the number of cuts and purpose of the grassland has to be taken into account (pasture, silage, hay). Generally the amounts of N, P and K used are clearly less than the recommended maximum values (Table 4).

Nitrogen has the largest effect on grass DM yield. The current maximum N rates for silage production are well below the biological maximum yield responses 330-350 kg N ha⁻¹ achieved in experiments (Salo *et al.*, 2013).

In addition to the environmental restriction of N-use, there is also an increased risk of winter damage. Potassium (K) has the second largest influence on DM yield of grass, but the effect is related to the mineral composition of soil material and is well explained by concentration of acid soluble K (K_{HCl}; Virkajärvi *et al.*, 2014). In a recent meta-analysis across 37 studies in Finland the overall response of grass DM yields to P fertilization (mean 50 kg P ha⁻¹) was 13% over the control (Valkama *et al.*, 2015) and the response diminished by increasing soil P concentration. An important feature of Finnish grassland management is that fertilizers are often applied as commercial compound fertilizers (NPKS) with varying composition (N, NS, NK etc.) and nutrient ratios. This means that targeted changes in nutrient ratios can only be made at paddock level.

In experiments, annual grass yields are between 9,000-12,000 kg ha⁻¹, typically achieved with an annual N rate of 200-250 kg ha⁻¹ and harvested 2 or 3 times per season. On farms the yield level is clearly lower, the median being 5,500 kg DM ha⁻¹ year⁻¹, but the fertilization intensity is also lower on commercial farms (i.e. 155 kg N ha⁻¹ year⁻¹; Field Parcel Registry of ProAgria Rural Advisory Services). However, there is substantial variation among farms and among paddocks on farms: for example, in a grass production competition by Yara Ltd. the winning farm had a mean yield of 13,200 kg DM ha⁻¹ year⁻¹ in the year 2012 (Luomaperä and Artjoki, 2012). The system of area-based subsidies and regulations concerning the area required for manure spreading per LU both lead to there being an excess field area (i.e. a low LU ha⁻¹) compared to biological maximum of LU ha⁻¹ that could be achieved. On the other hand, this provides flexibility for the production system, and decreases the fertilization demand relative to the maximum figures (Regina *et al.*, 2014).

Animal manure

Animal manure has received a lot of attention during the last decades, mainly because of its large potential environmental impact. Many research reports have been published about best practices and new technologies in the spreading and transportation of manure, and life cycle analysis to estimate

Table 4. Annual nutrient use (total nutrients, kg ha⁻¹) in fertilizer for grassland cut for silage (2-3 cuts year⁻¹)

	Nitrogen	Phosphorus	Potassium	Source
Maximum	160-240	0-46	0-170	Finnish Agri-Environmental Scheme 2015 (draft)
In farm surveys	150-160	15	66	ProAgria Field Parcel registry 2014, n=16,100 parcels in years 2005-2012

environmental effects (see e.g. Luostarinen *et al.*, 2011). However, the general problem still remains: low DM (and nutrient) concentration in slurry makes it expensive to transport over long distances. On the other hand, farmyard manure (FYM) is not used effectively in modern grass-dominated crop rotations.

In Finland the livestock unit (LU) density on dairy farms is relatively low and it seems that the problem of local concentration of manure and nutrients is less challenging on dairy farms than on pig and poultry farms. This is mainly due to the use of grass-silage-based diets on dairy farms, which ensure the low LU density per ha and, consequently, enables the slurry spreading area to be large enough for the amount of slurry produced. Typical amounts applied are in the range 20-40 Mg ha⁻¹ year⁻¹ in one or two applications. As manure contains 3.0 g N, 0.5 g P and 2.9 g K kg⁻¹ of fresh weight (Viljavuuspalvelu, 2015), the amounts of nutrients are in the ranges of 60-120 kg N, 10-20 kg P and 58-116 kg K ha⁻¹. The proportion of farms using slurry systems is 63% and FYM is 36% (Grönroos *et al.*, 2009). Data obtained from a small number of farm surveys show that the soil P status is not exceptionally high on dairy farms, nor is it high in the most typical dairy production areas (Viljavuuspalvelu, 2015).

Dairy production and environment

Environmental impacts caused by dairy farming in Finland include nutrient losses in surface runoff and by leaching, and gaseous emissions from fields and farms. Gaseous losses from agriculture (5.7 Mt CO₂-eq) are about 9% of the total of all greenhouse gas (GHG) emissions (2012 data) in Finland (Statistics Finland, 2014). In 2008 milk production contributed 28% of the total GHG emissions from agriculture. The largest source of GHG emissions is agricultural soils, especially organic soils, which contributed 61% of the total emissions from agriculture. The proportion is high compared to other EU countries (Leip *et al.*, 2010). Thus, it is almost impossible to mitigate GHG emissions significantly without measures that affect the management and area of organic soils. Mitigation of gaseous losses is an important issue as there is a national Intergovernmental Panel on Climate Change (IPCC) reduction target to be met (-13%, 0.76 Mt CO₂-eq of the emissions in 2005 reduced in 2020, Regina *et al.*, 2014). The average CO₂-eq emissions from milk production are ca. 0.5 kg of CO₂-eq kg⁻¹ milk higher than the average emissions in EU countries (1.4 kg of CO₂-eq kg⁻¹ milk on EU average; Leip *et al.*, 2010) this difference being mainly due to the forage production on organic soils. Agriculture contributes over 90% of total ammonia emissions in Finland, being 30,000 Mg y⁻¹. Most of this (60%) originates from manure. Dairy production accounts for approximately one-third of the total amount of ammonia emissions from agriculture (Grönroos *et al.*, 2009).

Unlike GHG emissions, the impacts of water-soluble nutrient losses are mostly local. In the most important dairy production areas about half the annual precipitation falls as snow, and snowmelt causes large pulses of runoff in springtime. Lakes are fairly shallow with complex spatial structures including small closed bay areas. Phosphorus is the main cause of eutrophication of surface waters. As large part of dairy production is located in proximity to inland lakes and rivers, the P load from surrounding fields can be substantial. The ecological quality of surface waters in the main milk production regions of the North-Savo and Ostrobothnia river area is below average (Aakkula and Leppänen, 2014). However, only a minor part of dairy production is located in areas that affect the most polluted part of the Baltic Sea, the Finnish Archipelago.

It has been proven that grasslands reduce erosion and, consequently, the transfer of particulate P from land to water. However, the concentration of dissolved P in surface runoff from grasslands can be high (Turtola and Kemppainen, 1998). There are several reasons for this. Freezing temperatures may damage the plant and microbial cells, which then release dissolved nutrients to the soil. Decomposing dung pats on pastures and surface-applied slurry and fertilizers are also known to increase the risk for dissolved P losses. Snow-melt water is effective in its ability to carry nutrients in solution, and as the amount of melt

water is high this may also increase the losses (Järvenranta *et al.*, 2014). Rätty *et al.* (2012) measured the total P-load from a grassland-based dairy production area in central Finland and found that it was slightly lower than the Finnish reference value from agricultural production in general (Vuorenmaa *et al.*, 2002). However, the proportion of dissolved P was much higher compared to the reference value and there was a great variation in the proportion of the dissolved P of the total P (from 8 to 93%). Losses of total N from dairy production area were 67% higher than the Finnish reference value from agricultural land. As expected, the losses of total solids were low compared to arable land (Puustinen *et al.*, 2007).

Surface-applied slurry causes a risk of P accumulation in the surface soil, which increases the risk for P losses in surface runoff after heavy rain or when soil is waterlogged or frozen. Average losses of 0.5-1.5 kg total P ha⁻¹ y⁻¹ have been measured from grasslands fertilized with surface-application of slurry. Surface-runoff losses of P can be minimized by using slurry-injection techniques, the use of which is quite common practice in Finland. The slurry is injected to 3-7 cm depth from the soil surface and P is adsorbed on to soil particles. This can decrease losses up to 80% (Uusi-Kämpä and Heinonen-Tanski, 2010).

In contrast to the surface run-off losses of P, losses of N by leaching are much more important than N losses in surface runoff. Most of the N-leaching from grasslands occurs in spring, but changing climate over recent years has resulted in increased autumn and winter losses. Nitrogen loss in surface runoff (mostly in the form of NH₄-N) is small and of minor importance. Winter conditions change the N dynamics in soil compared to areas where soil does not freeze. Microbial activity slows down, but still continues even at temperatures below zero (Maljanen *et al.*, 2009). Freezing prevents most water movement in soil and NO₃-N accumulates in the soil. Nitrate discharges in spring through leaching and gaseous losses when the soil thaws and snow cover (often containing over 130 mm water) melts. Sward renewal is the critical point of the N cycle in short-term leys. A mineralization pulse causes large N losses especially from pastures (60 kg N ha⁻¹) through leaching (Saarijärvi, 2008).

In Finland it is a common practice to use slurry as a fertilizer for the second cut of grass and again in autumn to empty the slurry storage before winter. In warm and dry conditions after the first cut, up to 20% of the surface-applied (broadcast) slurry total N may be lost through NH₃ volatilization. However, the injection technique almost fully prevents NH₃ volatilization (Uusi-Kämpä and Mattila, 2010). The leaching losses of N are more likely to occur in autumn and spring than during summer months and up to 40 kg year⁻¹ total N leaching losses have been measured after spreading slurry twice during the growing season (summer and autumn; Virkajärvi, unpublished). After several years of repeated slurry applications to the grassland, as is usual in dairy farming, the risk for N leaching increases (Saarijärvi, 2008; Uusi-Kämpä and Mattila, 2010).

According a dairy farm survey (Virtanen and Nousiainen, 2005) the typical N and P farmgate balances in Finland were 109 (±41) and 12 (±7.2) kg ha⁻¹ respectively. The most significant inputs into the system were fertilizers (100 and 9 kg ha⁻¹ for N and P respectively) and concentrates (39 and 7 kg ha⁻¹ for N and P, respectively) and the most important outputs were nutrients in milk exported from the farm (23 and 7 kg ha⁻¹ for N and P, respectively).

Profitability and market environment

During the past century the Finnish dairy sector has been able to maintain a relatively stable and high price for milk. Between 2000 and 2013, the average producer price has been 22% higher than the average of EU-15 countries. The high producer price is the result of the co-operative structure of the dairy industry and high added value for the products. The durability of the co-operative chain became clearly visible during the world market price crisis in 2008, when profitability fell more in many other countries than it did in Finland (Jansik *et al.* 2014). Profitability of milk production has stayed below the EU-27

average, but remained relatively stable. During 2006-2012 the profitability ratio has varied between 0.40-0.67, while in EU-27 the average has been 15% higher, varying between 0.49-0.73 (Profitability ratio of 1.0 indicates that all production costs including country specific interest demand for capital and costs of family factors have been covered).

Self-sufficiency in milk products (primary equivalent, excluding butter) was 102% in 2011 (FAOSTAT, 2015). The total consumption of milk products has slightly increased in the past years. According to FAO (2007) the per capita consumption of milk in Finland is the highest in the world (361 kg year⁻¹). However, demand for domestic products has remained stagnant and the increased demand has been filled mainly by imports. The value of imported milk products tripled between 2002 and 2013, to M€ 377. For example, over the years 2002-2013, the proportion of cheese that was provided by imports increased from less than 20% to 51% of total consumption (Jansik *et al.*, 2014). Measured by value, the biggest suppliers of imports in 2013 were Sweden (34%), Germany (32%) and Denmark (9%). The location of Finland offers some geographical border protection for fresh dairy products, which are not easily transportable; therefore imports of fresh milk have stayed at a much more modest level compared to cheese and yoghurts (Jansik *et al.*, 2014). However, abolition of milk quotas is expected to increase European milk production, which may increase imports by Finland as well.

Export markets provided 20% of the dairy industry sales in 2012 (Jansik *et al.*, 2014). In 2013 Finland exported milk products mainly to Russia (48% of the total export value) and Sweden (19%). The volume of exports has increased by 45% over the years 2002-2013, while the export value increased by 60%. The greater increase of value, relative to volume, shows that so far exports have been able to concentrate more on high value products. The dairy industry has invested in better utilization of milk components and focused on high-value products like functional foods. A significant part of the fat-component of the milk is used in products that are exported, while protein is demanded domestically.

In 2013 the trade value balance of dairy products was positive by 162 M€ (Finnish Customs, 2014) which was achieved by exports higher value compared to lower value imports. The positive value balance, if compared directly to annual milk production, was 13.6 cents per litre (2,200 million l). Restrictions in trade with Russia, which were put in place in 2014, have seriously hit the Finnish milk industry.

Production cost

According to Finnish Farm Accountancy Data Network (FADN) results, the costs of purchased and produced feed account for one third of the total production cost of milk (Table 7), labour has the second biggest share, and the third is the animal cost, consisting mostly of replacement costs. Housing costs and related maintenance costs are also significant, because of small farm size and northern conditions, which require more farm buildings than is often the case in southern European countries. Fully comparable FADN-based calculations are not available for competing countries but, for example, according to International Farm Comparison Network (IFCN) farm comparisons, among European countries the production cost is higher only in Switzerland for average sized farms (Hemme *et al.*, 2014). According to Ovaska and Heikkilä (2014), the most significant cost disadvantages compared to competing countries were machinery, labour and other miscellaneous costs. Labour input per cow was 207 h year⁻¹ cow⁻¹ in the research period. For example in Denmark and the Netherlands, this figure ranged from 34 to 52 h year⁻¹ cow⁻¹. The high production cost is also partly compensated by support payments, such as nationally paid northern aid. It is paid on a per-litre basis, and the support is higher in northern regions. The average of litre-based direct payments was 7.47 cents per litre in 2013. In southern Finland, after 2015 support is to be paid on a per-head basis.

Table 7. Unit cost structure of milk per litre in 2013, all farm sizes (Luke, EconomyDoctor 2015)

	Cents per litre	Proportion
Feed (purchased and self-produced)	25.2	33%
Animal cost	12.8	17%
Fuel and electricity	2.9	4%
Maintenance of buildings and machinery	5	7%
Insurance, rents and other costs	6.1	8%
Machinery depreciation and interest	4.6	6%
Building depreciation and interest	5.2	7%
Other interests (debt)	1.2	2%
Labour	13.3	17%
Total cost per litre	76.3	100%

Due to relatively high labour costs and the strenuous nature of the work, construction of new barns is capital-intensive; for example, adopting an automatic milking system is usual. The production cost varies according to farm size and efficiency. The best farms can produce milk with costs of 68-74 cents per litre, while the average of all farms was 80 cents per litre (Latukka and Vilja, 2014). Only costs were accounted for in the calculation. Because the profitability ratio was 52% in 2013, only a proportion of the unit cost of labour and interest costs are realized. If accounted for, area payments would also lower the net production costs of self-produced feeds.

Future challenges

Maintaining profitability of dairy farms in the future is one of the main challenges. Increasing production in Europe after quota abolition in 2015 may increase the supply of imported milk products to the domestic market and make it more difficult to maintain the high producer price. Previously, the price of milk has been above EU-27 average, which has compensated for the high production costs associated with northern conditions. Profitability is connected to farm efficiency, which is further related to the unit cost of milk. Increasing the farm size has been shown to increase productivity; therefore investment subsidies are justified. However, growth should be sustainable and should not lead to over-indebtedness, or slow down the total factor productivity growth by excessive capital costs. Profitability is also connected to the abilities for investing in new technology, which might improve, for example, animal welfare and improve the working conditions of the farmers. Poor profitability is also related to farmland degradation, which may increase environmental load.

Finnish farms are usually family farms, where ownerships are changed by generational shifts. In the past years, low profitability has had a negative impact on the attractiveness of farming as a profession. Heavy structural change is partly due to the unsatisfactory wage, in relation to the workload on a dairy farm. However, lower rates of return are often accepted in agricultural enterprises. Rural areas may not offer many options for full-time work and milk production may offer relatively high living standards compared to other options in the region. The inspiring examples of young farmers investing successfully, the support of local authorities and the attitude of local banks have strong influences that can explain why milk production may increase, or decline, even in neighbouring municipalities (Jansik *et al.*, 2014).

The domestic dairy market is mature, but fluctuations in demand and diet trends are becoming more common. Growing supply within EU internal markets will also increase the sensitivity of the Finnish dairy chain to world market disorders.

A very general challenge is to combine economically viable production with environmental and ethical demands, often referred to as sustainable intensification or resource-efficient production. Work has to be done to find the most cost-effective measures, e.g. for water protection and reducing gaseous emissions from dairy production. Often these measures must be especially tailored for dairy farms (dissolved P, NH₃ emissions, etc.). Slurry injection techniques can solve some of the manure-related problems but more technological innovations are needed to solve other problems, e.g. the logistic problems of large farms with scattered farm structures. The most difficult part is to keep the cost of such solutions at a reasonable level.

One challenge is to fulfil the protein demand of high producing dairy cows with domestic protein sources. Faba bean (*Vicia faba* L.) may provide one alternative for protein production in addition to the commonly used rape seed (*Brassica rapa* var. *oleifera* DC; *B. napus* var. *oleifera* DC), but it will need favourable growing conditions. Soybean (*Glycine max* L.) is currently not an option in Finland due to the climatic conditions; however, these might change and become more favourable for lucerne and faba bean due to climate change.

The effects of projected future climate change provide both threats and opportunities. Increasing variability in weather conditions will force farmers to have buffers in their forage production, which will increase their production costs. On the other hand, Finnish dairy production will most likely benefit from climate changes that lead to an extended growing season and the possibility of adopting new protein and forage species. Full utilization of these projected positive climate changes may require some upward adjustment of the current nutrient-use regulations, which is very much against the current trend.

Finland has many strengths in its milk production chain such as well functioning infrastructures, ample water resources, animals of high genetic quality, top quality milk and, first and foremost, dedicated and highly qualified professional dairy farmers. The estimated impacts of climate change show that the feed production conditions may even improve in northern Europe, which may improve the relative competitiveness of the Finnish dairy industry in the global context. The key factor is to improve the economic efficiency of dairy farming by keeping in mind the occupational health of the dairy farmers, product quality, animal welfare and environmental constraints.

References

- Aakkula J. and Leppänen J. (eds.) (2014) *Maatalouden ympäristötuen vaikuttavuuden seurantatutkimus (MYTVAS 3). Loppuraportti*. [The effectiveness of environmental subsidies. Follow-up study. (MYTVAS 3) Final Report] Maa- ja metsätalousministeriö 3/2014. 265 s. [In Finnish].
- Bélangier G., Rochette P., Castonguay Y., Bootsma A., Mongrain D. and Ryan D.A.J. (2002) Climate change and winter survival of perennial forage crops in Eastern Canada. *Agronomy Journal* 94, 1120-1130.
- EEA (2015) *Annual number of days with snow cover over European land areas 1961-1990 and projected change for 2071-2100*. Available at: <http://tinyurl.com/n5xs5hx>.
- ECA&D (2015) Country info. Available at: <http://tinyurl.com/ovkoxdu>.
- FAO (2007) *Current worldwide total milk consumption per capita*. Available at: <http://chartsbin.com/view/1491>.
- FAO (2010) *Greenhouse gas emissions from the dairy sector a life cycle assessment*. Food and Agriculture Organization of the United Nations Animal Production and Health Division, Rome, Italy. 98p.
- FAOSTAT (2015). Food Balance Sheets. FAO Statistics Division, Rome, Italy. Available at: <http://faostat3.fao.org>.
- Finnish Customs (2014) Foreign trade statistics. Available at: http://www.tulli.fi/en/finnish_customs/statistics/index.jsp.
- Grönroos J., Mattila P., Regina K., Nousiainen J., Perälä P., Saarinen K and Mikkola-Pusa J. (2009) *Development of the ammonia emission inventory in Finland*. The Finnish Environment 8, 63p.

- Halling M., Paul C., Soether U., Nissinen O., Tuori M., Hopkins A., Lister S. and Doyle C.J. (2002) Production and nutritive quality of forage legumes for silage. In: Wilkins, R.J. *Low-input animal production based on forage legumes for silage (LEGSIL)*. Final report. IGER, UK, pp. 26-104.
- Heikkilä A.-M. (2013) Replacement decisions on Finnish dairy farms: toward better economic performance with novel technology and sustainable herds. *MTT Science* 22. MTT, Helsinki, Finland, 38 p.
- Hemme T. (2014) The IFCN Dairy Report 2014. For a better understanding of the dairy world, IFCN Dairy Research Center.
- Huhtamäki T. (2014) Ruokinnan teemavuodesta nuorkarjan teemavuoteen [Results from on-farm feed consumption results] Available at: http://www.proagria.fi/sites/default/files/attachment/tuse-lehmien_rehunkulutus2013_paivitetty_tilaseosten_osalta_heinak2014.pdf.
- Huhtanen P., Rinne M. and Nousiainen J. (2007) Evaluation of the factors affecting silage intake of dairy cows: a revision of the relative silage dry-matter intake index. *Animal* 1, 758-770.
- Huhtanen P., Rinne M., and Nousiainen J. (2008) Evaluation of concentrate factors affecting silage intake of dairy cows: a development of the relative total diet intake index. *Animal* 2, 942-935.
- Huhtanen P., Rinne M. and Nousiainen, J. (2009) A meta-analysis of feed digestion in dairy cows. 2. The effects of feeding level and diet composition on digestibility. *Journal of Dairy Science* 92,5031-5042.
- Huhtanen P., Rinne M., Mäntysaari P. and Nousiainen J. (2010) Integration of the effects of animal and dietary factors on total dry matter intake of dairy cows. *Animal* 5, 691-702.
- Huhtanen P. and Nousiainen J. (2012) Production responses of lactating dairy cows fed silage-based diets to changes in nutrient supply. *Livestock Science* 148, 146-158.
- Huhtanen P., Jaakkola S. and Nousiainen J. (2012) An overview of silage research in Finland: from ensiling innovation to advances in dairy cow feeding. In: Kuoppala K., Rinne M. and Vanhatalo A. (eds.) *Proceedings of the XVI International Silage Conference*, Hämeenlinna, Finland, 2-4 July 2012. MTT Agrifood Research Finland, University of Helsinki, Finland, pp. 16-33.
- Höglind M., Thorsen S.M. and Semenov M.A. (2013) Assessing uncertainties in impact of climate change on grass production in Northern Europe using ensembles of global climate models. *Agricultural and Forest Meteorology* 170, 103-113.
- Jansik C., Irz X. and Kuosmanen N. (2014) *Competitiveness of Northern European dairy chains*. Publication 116. MTT Economic Research, Agrifood Research Finland, Helsinki, Finland.
- Järvenranta K., Virkajärvi P. and Heinonen-Tanski H. (2014) The flows and balances of P, K, Ca and Mg on intensively managed Borel high input grass and low input grass-clover pastures. *Agricultural and Food Science* 23, 106-117.
- Kersalo J. and Pirinen P. (2009) *Suomen maakuntien ilmasto* [The climate of Finnish regions]. Finnish Meteorological Institute, Report 2009:8. 185 pp. [In Finnish with English abstract].
- Kangas A., Laine A., Niskanen M., Salo Y., Vuorinen M., Jauhiainen, L. and Nikander H. (2006) Results of official variety trials. MTT:n Selvityksiä 105. 210p. [In Finnish]
- Latukka A. and Vilja M. (2014) What a litre of milk costs: knowing the production costs helps to develop profitability. In: Niemi, J. and Ahlsted, J. (eds) *Finnish agriculture and rural industries*. MTT, Helsinki, Finland, pp. 64-65.
- Leip A., Weiss F., Wassenaar T., Perez I., Fellmann T., Loudjani P., Tubiello F., Grandgirard D., Monni S. and Biala K. (2010) *Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) – final report*. European Commission, Joint Research Centre.
- Luke (2014) *Feed tables and feeding recommendations*. Available at: www.mtt.fi/feedtables.
- Luke (2015) *Economy doctor*. Available at: <https://portal.mtt.fi/portal/page/portal/economydoctor>.
- Luomaperä S. and Artjoki H. (2012) Nurmen satokilpailun tulokset 2012 [Results of yield competition 2012]. *Leipä Leveämmäksi* 3/2012, 28-29. [In Finnish].
- Luostarinen S. Logrén J., Grönroos J., Lehtonen H., Paavola T., Rankinen K., Rintala J., Salo T., Ylivainio K. and Järvenpää M. (2011) *Sustainable utilization of manure*. MTT report 21. MTT Jokioinen, Finland, 164 p.
- Madsen J., Hvelplund T., Weisbjerg M.R., Bertilsson J., Spörndly R., Olsson I., Harstad O.M., Volden H., Tuori M., Varvikko T., Huhtanen R. and Olafsson B.L. (1995) The AAT/PBV protein evaluation system for ruminants. A revision. *Norwegian Journal of Agricultural Science Supplement* 19, 1-37.
- MAFF (1975) *Energy allowances and feeding systems for ruminants*. Technical Bulletin 33. Her Majesty's Stationery Office, London, UK. 79 p

- Maljanen M., Virkajärvi P., Hytönen J., Öquist M., Sparrman T. and Martikainen P.J. (2009) Nitrous oxide production in boreal soils with variable organic matter content at low temperature – snow manipulation experiment. *Biogeosciences* 6, 2461-2473.
- Manninen E. (2013) Automaattilypsy jatkaa kasvuaan. *Maito ja me* 3/2013, 48. [In Finnish].
- MMM (2000) VnA 931/2000. Valtioneuvoston asetus maataloudesta peräisin olevien nitraattien vesiin pääsyn rajoittamisesta. Available at: <http://www.finlex.fi/fi/laki/alkup/2000/20000931>. [In Finnish].
- Niskanen O. and Heikkilä A-M. (2014) Selvitys parsinavettojen taloudellisesta merkityksestä nautasektorilla. In: Raussi S. (ed.) [*Well-being- and economic effects of cattle stalls types*]. Eläinten hyvinvointikeskus, Helsinki, Finland, pp. 22-39. [In Finnish].
- Niskanen O. and Heikkilä A-M. (2015) The impact of parcel structure on the efficiency of Finnish dairy farms. *Agricultural and Resource Economics Review* 44/1 (in press).
- Nissinen O. and Hakkola H. (1994) *The effect of the harvesting method and plant species on the grassland productivity in North Finland*. Maatalouden tutkimuskeskus, Tiedote 19/1994. 48 p. [In Finnish with English summary].
- OSF (2015) Official Statistics Finland. Information centre of the Ministry of Agriculture and Forestry. Available at: <http://tinyurl.com/ncjbe2t>.
- Ovaska S. and Heikkilä A.-M. 2012. *Suomen maitotilojen rakennekehitys ja kilpailukyky IFCN-tyyppitilataarkastelu 2001-2011*. MTT raportti 126. MTT, Helsinki, Finland. [In Finnish]
- Peltovuori T. (2006) *Phosphorus in agricultural soils of Finland – characterization of reserves and retention in mineral soils*. Doctoral dissertation, Univ. Helsinki, Finland, 69 p.
- Pulli S. (1980). Growth factors and management technique used in relation to the developmental rhythm and yield formation pattern of a pure grass stand. *Journal of Scientific Agricultural Society of Finland* 52, 281-330.
- Puustinen M., Tattari S., Koskiahjo J. and Linjama J. (2007) Influence of seasonal and annual hydrological variations on erosion and phosphorus transport from arable areas in Finland. *Soil and Tillage Research* 93, 44-55.
- Regina K, Lehtonen H., Palosuo T. and Ahvenjärvi S. (2014) *Maatalouden kasvihuonekaasupäästöt ja niiden vähentäminen*. MTT Raportti 127. 43 p. [In Finnish with English summary].
- Riesinger P (2010) *Agronomic challenges for organic crop husbandry*. Doctoral dissertation, Univ. Helsinki, Finland, 412 p.
- Räty M. Saarijärvi K, Virkajärvi P. Saarijärvi E. and Kröger H. (2014) *Jatkuvatoiminen ravinnekuormituksen seuranta verkosto Kirmanjärven valuma-alueella*. [Nutrient load from Kirmanjärvi catchment area measured by continuous monitoring system.] Suomen Maataloustieteellisen Seuran Tiedote No 30. 7 p. [In Finnish].
- Saarijärvi K. (2008) *Nitrogen cycling on intensively managed boreal dairy pastures*. Doctoral dissertation. Agrifood Research Reports 134. MTT Agrifood Research Finland, Jokioinen, Finland, 134 p.
- Saarinen E, Virkajärvi P., Hyrkäs M., Suomela R., Niskanen M., Salo K. and Huuskonen A. (2012) Maissin soveltuvuus rehuksviksi Keski-Suomessa. [Suitability of maize as fodder crop in Central Finland]. In: Huuskonen A. (ed.) *Novel crop options for cattle*. MTT report 77. MTT, Jokioinen, 75 p.
- Salo T., Eurola M., Rinne M., Seppälä A., Kaseva J. and Kousa T. (2014) *The effect of nitrogen and phosphorus concentrations on nutrient balances of cereals and silage grass*. MTT Report 147. MTT, Jokioinen, Finland. 36 p.
- Soil Atlas of Europe (2005) Soil Bureau Network, European Commission, Office for official publications of the European Communities, Luxembourg, Luxembourg, 128 p.
- Statistics Finland (2014) *Greenhouse gas emissions in Finland 1990-2012*. National Inventory Report under the UNFCCC and the Kyoto Protocol 15.4.2014. Available at: <http://www.stat.fi/greenhousegases>.
- Turtola E. and Kempainen E. (1998) Nitrogen and phosphorus losses in surface runoff and drainage water after application of slurry and mineral fertilizer to perennial grass ley. *Agricultural and Food Science in Finland* 7, 569-581.
- Uusi-Kämpä J. and Heinonen-Tanski H. (2008) Evaluating slurry broadcasting and injection to ley for phosphorus losses and fecal microorganisms in surface runoff. *Journal of Environmental Quality* 37, 2339-2350.
- Uusi-Kämpä J. and Mattila P.K. (2010) Nitrogen losses from grass ley after slurry application-surface broadcasting vs. injection. *Agricultural and Food Science*, 19, 327-340.
- Valkama E. Uusitalo R., Ylivainio K. Virkajärvi P. and Turtola, E. (2009) Phosphorus fertilization: a meta-analysis of 80-year research in Finland. *Agriculture, Ecosystems & Environment* 130, 75-85.
- Viljavuuspalvelu (2015) Lantatilasto 2005-2009. Available at: <http://tinyurl.com/ohbmqax>. [In Finnish].
- Virkajärvi P. (2005) Milk production on pasture in Finland. *Gronn Kunnskap* 9: 58-62.

- Virkajärvi P. and Järvenranta K. (2001) Leaf dynamics of timothy and meadow fescue under Nordic conditions. *Grass and Forage Science* 56, 294-304.
- Virkajärvi P., Sairanen A. and Nousiainen J. (2003) Sward and milk production response to early turnout of dairy cows to pasture in Finland. *Agricultural and Food Science in Finland* 12: 21-34.
- Virkajärvi P., Kykkänen S., Rätty M., Hyrkäs M., Järvenranta K., Isolahti M. and Kauppila R. (2014) *Potassium fertilization of grass in Finland. Use of soil acid-soluble potassium as a basis for potassium fertilization*. MTT raportti 165. MTT Jokioinen, Finland, 52 p.
- Virkajärvi P., Maljanen M., Saarijärvi K., Haapala J. and Martikainen, P.J. (2010) N₂O emissions from boreal grass and grass-clover pasture soils. *Agriculture, Ecosystems & Environment* 137, 59-67.
- Virkajärvi P., Pakarinen K., Hyrkäs M., Seppänen M. and Bélanger G. (2011) Tiller characteristics of timothy and tall fescue in relation to herbage mass accumulation. *Crop Science* 52, 970-980.
- Virtanen H. and Nousiainen J. (2008) Nitrogen and phosphorus balances on Finnish dairy farms. *Agricultural and Food Science* 14, 166-180.
- Vuorenmaa J., Rekolainen S., Lepistö A., Kenttämies K. and Kauppila P. (2002) Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. *Environmental Monitoring and Assessment* 76, 213-248.
- Vuorinen J. and Mäkitie O. (1955) The method of soil testing in use in Finland. *Agrogeology Publication* 63, 1-44.
- Welfare Quality* (2009). Welfare Quality* assessment protocol for cattle. Welfare Quality* Consortium, Lelystad, the Netherlands.