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The flows and balances of P, K, Ca and Mg on intensively managed Boreal high input grass and low input grass-clover pastures

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The main objective of the study was to compare nutrient balances of phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca) on fertilized grass pasture (high input) and unfertilized grass-clover pasture (low input) both grazed by dairy cattle. The second aim was to quantify P loss in surface runoff from the fertilized grass pasture. The study was conducted on a lysimeter field that included two surface runoff collector ditches. The whole area was rotationally stocked five times per year and the amount of milk was recorded. Nutrient balances were negative on both grass and grass-clover pastures except the P balance for grass pasture, which was 18 kg ha^{-1} positive. The amount of total P in the surface runoff from fertilized grass pasture was 1.2–0.9 kg ha^{-1} y^{-1}. It seems that in short-term ley farming, grass-clover swards can retain nutrients in the soil better than pure grass swards.

Key words: grazing, leaching, surface runoff, nutrient balance

Introduction

Both high and low input ley rotation systems in Nordic conditions have different mineral cycling dynamics than long-term or permanent grasslands in temperate climate. Renovating the sward by cultivation and reseeding every three to four years, which is typical for Nordic management, destroys the vegetation, mixes the surface soil to 20–30 cm depth and thus regularly changes the soil structure. On long term or permanent grasslands, the surface soil remains intact, nutrients are cumulated and stratified to soil surface and root systems is larger and deeper than on short term leys (Whitehead 2000).

In Central Finland, the main dairy production area of the country, the harsh winter conditions pose challenges for production. The soil freezes to > 20 cm depth and the snow cover period can last over 5 months per year. Approximately 50% of the precipitation falls as snow. Occasionally, the temperature can drop below –30 °C. This may cause damage to plant and microbial cells and lead to nutrient losses during snow melt as the water flushes the soluble nutrients to the deeper soil layers, ground water and surface waters (Edwards et al. 2007, Räty et al. 2010). Nutrient flows have been studied often on permanent pastures or long-term leys in temperate climates with rather mild winter conditions (Haynes and Williams 1993, Whitehead 2000, Withers et al. 2001) but the nutrient dynamics – especially phosphorus and cations - on short-term Boreal pastures are not well known.

Mineral inputs to high input managed pastures in Nordic areas consist mainly of fertilizers (for K and P), lime (for Ca and Mg), with some additional mineral and concentrate feeds given to cows. On low input or organic pastures the use of fertilizers is limited. Lime products are applied regularly to both types of pastures to maintain the soil pH. On some areas that are rich in clay or silicate minerals like mica, weathering of these minerals acts as an abundant source of K, but on the other areas K fertilization or slow K-releasing materials like biotite are used to provide K inputs. Atmospheric deposition is a negligible input for all these mineral nutrients.

On intensive dairy pastures where the grass utilization is often less than 60%, senescence of rejected herbage can result in release of some plant nutrients to the soil surface (Whitehead 2000). The presence of clover (*Trifolium* spp.) in the sward changes the nutrient dynamics as the herbage nutrient concentration differs from grass and the fertilization is often lower than for grass pasture. Clover root structure is different and root turnover rate is higher than grass for roots and this may also change the soil nutrient dynamics (Rasmussen et al. 2010).

Areas of pastures on which animal excreta are concentrated can become hot spots for nutrient cycling. Nutrient concentrations beneath excretal patches usually exceed the plant requirements and may be high enough to cause damage to vegetation (Haynes and Williams 1993). Thus there is increased risk for nutrient losses to occur, particularly from beneath dung and urine patches.

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The major pathways of nutrient output or removal from Boreal dairy pastures are milk, excretion during milking, leaching and surface runoff. Excretion during milking is an important output pathway, though it is often neglected (Saarijärvi 2008). Only small amounts of nutrients are retained in dairy cows weight gain, placental and foetal growth, and gaseous losses of non-nitrogenous nutrients are nonexistent or negligible (McDonald 2002).

Partitioning between output pools differs between nutrients depending on the environmental circumstances and nutrient availability in the soil and aboveground biomass. Nordic winters have a major impact on the yearly water dynamics and consequently on partitioning between surface runoff and leaching (Sutinen et al. 2008). This has a major impact on nutrient-loss dynamics within the year, as surface runoff and leaching through the soil matrix differ in their concentrations of nutrient elements (Owens et al. 1998, 2003). Partitioning of nutrient elements between surface runoff and leaching is also dependent on the cultivation practices and soil properties, e.g. structure, texture, cation exchange capacity (CEC), organic matter content and pH (Haygarth and Jarvis 1999).

There have been many articles of phosphorus and nitrogen cycling and their environmental effects on grasslands and pastures (e.g. reviewed by Withers et al. 2001, Saarijärvi 2008). However, the results on flows of macronutrients such as Ca, Mg and K on pastures are seldom reported (Owens et al. 1998, 2003). Macronutrients are of major importance in plant nutrition and inadequate amounts of these nutrients in the diets of dairy cows are suggested to be the primary reason for hypocalcaemia and hypomagnesaemia (Goff 2006).

It is well known that the permanent vegetation cover decreases the losses of particulate P from the soil, compared with tilled soil, but simultaneously it may also increase soluble P loss to surface waters (Räty et al. 2010). On grasslands high soil soluble P concentration increases P losses through surface runoff, which increases the risk of eutrophication of the surface waters (Pote et al. 1996). The role on soluble phosphorus is enhanced, as the excreta and fertilizers are surface supplied. The high soil P is a potential risk as the surface waters are naturally poor in P and thus sensitive to external P load (Arvola et al. 2011).

The main aims of this study were to compare nutrient flows on intensively managed dairy grass pasture (G) and low-input grass-clover pasture (GC) under the conditions of a Boreal climate and to calculate the nutrient balances for the main nutrients. Results concerning N are reported in Saarijärvi et al. (2007) and in this report we focus on the Ca, Mg, K and P. A further aim was to quantify P loss in surface runoff from grass pasture.

Materials and methods

A four-year study was undertaken at Agrifood Research Finland, Maaninka (63°10/N, 27°18/E, 88 m a.sl.). The soil was classified as medium-textured Dystric Regosol. The average depth of the groundwater was 5.2–5.8 m from the soil surface. The soil profile to 60 cm depth was composed of 7, 5, 12, 22, 43, 10 and 1% of particle sizes <0.002, 0.002 – 0.006, 0.006–0.02, 0.02–0.06, 0.06–0.2, 0.2–0.6, and 0.6–2 mm, respectively. The precipitation, temperature, frost depth and snow cover were measured at the official meteorological station located 200 metres from the study area.

Pasture management and herbage sampling

The sward was sown in spring 2000 without a cover crop. The seed composition of the G treatment was timothy (*Phleum pratense* L. cv. ‘Tuukka’), 7.0 kg ha^{-1}, meadow fescue (*Festuca pratensis* Huds. cv. ’Kasper’) 9.5 kg ha^{-1}. The composition of the GC treatment mixture was white clover (*Trifolium repens* L. cv. ‘Aberherald’), 4.5 kg ha^{-1}, Alsike clover (*Trifolium hybridum* L. cv. ’Frida’), 1.3 kg ha^{-1}, timothy (cv. ‘Tuukka’), 6.6 kg ha^{-1}, meadow fescue (cv. ‘Kasper’), 8.2 kg ha^{-1}, and smooth meadow grass (*Poa pratensis* L. cv. ‘Balin’), 3.3 kg ha^{-1}. During the first three years of the study the lysimeters were rotationally grazed by dairy cows, four or five times per growing season The G treatment was fertilized with 220 kg N, 23 kg P and 90 kg K ha^{-1} year^{-1}, divided into three applications, in 2001–2003. The GC treatment received no fertilizers. The field was irrigated by row sprinklers with 40 mm of water in July 2002, due to a long-lasting dry period.

The cows were grazed using a herbage allowance (HA) of 25 kg of dry matter (DM) cow^{-1} d^{-1} In rotational grazing system this lead to stocking rate of 4.4 and 4.0 cows ha^{-1} in G and GC treatments, respectively. Herbage mass (HM) was measured to 7 cm stubble height (pasture management described in more detailed in Saarijärvi et al. 2007). Cows were also given 6 kg d^{-1} of cereal based concentrates during the whole experiment (equals to 15.5 kg P, 23 kg K, 29 kg Ca, 9.5 kg Mg ha^{-1} year^{-1}). The cows were milked twice a day, the milk yield was recorded and individual milk samples were analysed for fat, protein, lactose and urea content. The energy-corrected milk (ECM) yield was calculated according to Tuori et al. (1996).

In May 2004, the area was ploughed and sown with a barley cover crop (*Hordeum vulgare* L. cv. 'Jyvä') at 50 kg ha^{-1}, and Italian ryegrass (*Lolium multiforum* L. cv. 'Turgo') at 25 kg ha^{-1} but not unfertilized. The forage was cut for silage in August 4 and grazed in 11–16 September.

Lysimeters, leachate sampling and soil sampling

The study was conducted on a 0.7 ha lysimeter field with a slope of 0.6% towards the water sample collection point. Eight plastic sheet wall lysimeters (10 m x 10 m x 1.8 m deep, collecting all the infiltrating water) were used in the experiment, with four being assigned to the G and four to the GC treatment. The amount of leachate was recorded and composite samples were collected by tipping bucket system every 15–20 mm. A detailed description of the lysimeter field is given in Saarijärvi et al. (2007).

The amount of surface runoff was recorded by tipping bucket system and composite samples were collected from two 400 m^2 by open shallow plastic bottom ditches every 10–15 mm. A hydrological year (1 June – 31 May) was used instead of the calendar year. Soil samples were taken from each lysimeter prior to the experiment and each year in autumn before soil frost. Soil samples from the surface soil (0–2 cm) and from the plough layer (0–25 cm) were taken from each lysimeter (n = 4) from both treatments at the beginning of the experiment (spring 2001) and at the end of the grazing years and in the autumn of 2005.

Chemical analyses of herbage, water and soil samples

The herbage, water and soil samples were chemically analysed at MTT, Jokioinen. The herbage samples were dried at 105 °C for 24 h and weight to determine the DM content. The subsamples for mineral analyses were dried at 60 °C for 24 h and P, Ca, Mg and K concentrations were measured (Huang and Schulte 1985) with ICP-OES. The air dry soil samples were analysed for soil pH (pH$_{H2O}$, 1:2.5 v/v), soluble Ca, Mg and P and exchangeable K using acid ammonium acetate -extractable pH 4.65, (Vuorinen and Mäkitie 1955) by ICP-OES, except P, which was analysed with a Skalar autoanalyzer. Water soluble P (P$_{H2O}$) was analyzed 2003 after the last grazing. Water extractions at a 1:100 soil-to-solution ratio, shaken continuously for 21 hours, filtered through a 0.2-µm Nuclepore® polycarbonate filter and analysed for molybdate-reactive P. The P concentration of the water extracts was determined colorimetrically (Murphy and Riley 1962) by Skalar autoanalyzer. The water samples were stored at 8 °C for 1–14 days and analysed for total P from unfiltered water samples after digestion with peroxisulphate in an autoclave (Finnish Standard Association, SFS, 3026) and PO$_4$-P after filtering (Nucleopore®, pore size 0.2 µm, SFS 3025) with Skalar autoanalyzer. Concentration of K, Ca and Mg were analyzed from filtered samples with ICP-OES.

Effect of grazing on calculation of balances

The amounts of mineral nutrients excreted in dung and urine during milking were estimated based on the difference between intake and output in milk (Saarijärvi et al. 2007). Retention in animal tissues was assumed to be zero over the grazing season. The mineral nutrient retention in gestation (foetus, placenta, uterus and mammary gland) was calculated based on nutrient in different tissues obtained from McDonald (2002).

Statistical analysis

The effect of treatments, G and GC, on herbage production, soil and water nutrient concentrations and the leached amounts was analysed using a SAS mixed models analysis of variance for a randomized complete block design (Littell et al. 2006). The data from the grass cover years in 2001–2003 were jointly analysed as repeated measurements. Annual means over each year per block were used in ANOVA. The data for the sward renewal year 2004–2005 were analysed separately. The mean values for the blocks were analysed (ANOVA) for the sum data for the whole ley rotation 2001–2005. The number of individual leachate samples during each treatment and year or period is presented in corresponding tables.

Results

Weather, leaching and surface runoff

The amounts of leachate from the lysimeters, the snow cover, frost depth, precipitation and temperature values, as well as the surface runoff from G treatment during the experiment, are presented in Table 1. Approximately 90% of the yearly leaching and surface runoff occurred during the short spring snowmelt period. During the sward renewal year of 2004, however, a considerable amount of leaching also occurred in summer. The amount of surface runoff was similar throughout the grazing years, being approximately 39% of the total amount of water leached and 15% of the average precipitation. Since the soil type is freely draining sand, even heavy (> 30 mm h^{-1}) rainfall events seldom result in much surface runoff.

Table 1. Precipitation, snow cover, snow water content, frost dates, lysimeter runoff and surface runoff of experimental years represented for hydrological years (1 June – 31 May).

Year	Precipitation mm	Snow cover dates	Snow water content mm	Frost dates	Frost depth cm	Lysimeter drainage mm	Surface runoff mm
2001–2002	498	14.11–25.4.	nd	5.11–1.5.	10	109	66
2002 –2003	521	6.11.–20.4.	144	18.10. –7.5.	31	129	99
2003–2004	625	21.11.–27.4.	138	9.12. –5.5.	26	196	107
2004–2005	672	15.11–24.4.	145	15.11. –22.4.	24	397	85

Soil pH and mineral concentrations

Soil pH at the beginning of the experiment was 6.02 and 6.15 in the G and GC treatments, respectively. After the grazing years in the autumn 2003, soil pH in the 0–25 cm layer was 5.75 and 5.90 in the grass and grass-clover treatments, respectively. There was no significant difference between the treatments. The soil mineral concentrations at the beginning and end of the experiment are presented in Table 2.

In the surface soil (0–2 cm), the soil P concentration was significantly higher in G than in GC treatment. There is also a clear rising trend in P concentration in the surface soil in the G treatment. This difference was also reflected in water-extractable P (P_{H2O}) of the surface layer at the end of grazing years, as the concentrations were 53.2 mg^{-l} and 15.7 mg^{-l} for G and GC, respectively (SEM 7.03 mg^{-l}, *p* =0.026). The difference was weaker and not statistically significant in the 0 –25 cm layer: P_{H2O} 16.2 mg^{-l} and 9.0 mg^{-l} for G and GC (SEM 3.7 mg^{-l}, *p* =0.20). There were no differences in the surface soil K concentrations, but Ca and Mg concentrations were lower in G than GC treatment. In the G treatment there was a tendency for surface soil Ca concentration to decrease each year (*p*= 0.09).

Also in the plough layer the soil P concentration was significantly higher in the G treatment than in the GC treatment at the beginning of the experiment. The soil K concentrations in the plough layer were similar in the G and GC treatments. Ca and Mg concentrations were significantly lower in the G treatment than in the GC treatment (Ca *p*-value = 0.04, Mg *p*-value = 0.01) and they stayed at lower levels throughout the experiment.

Herbage production and grazing

The swards of both treatments were almost equally productive in terms of their HM production. Only during the third grazing year was the HM of the GC treatment lower than the G treatment. Calculated intake of gross HM was 58% of the allowance. Energy corrected milk production per cow was 27.1 kg d^{-1} which was equal to 1.08 kg kg^{-1} gross herbage mass available per cow in both treatments. Herbage P and K concentrations were slightly higher in the G treatment than in the GC treatment, but Ca and Mg concentrations in herbage were much lower in the G than the GC treatment (Table 3).

Table 2. P, K, Ca and Mg concentrations in the soil before the experiment in autumn 2000, during grazing years 2001–2003 and after sward renewal (ploughing, barley+Italian ryegrass in 2004) in spring 2005. SEM indicates the standard error of mean (n = 4 per treatment, tr), G = grass, GC = grass-clover.

		P mg l^{-1}		K mg l^{-1}		Ca mg l^{-1}		Mg mg l^{-1}	
		G	GC	G	GC	G	GC	G	GC
0–2 cm	2000	9.1	6.1	99	104	852	1066	83	105
	2001	14.5	6.4	244	288	626	1019	78	111
	2002	19.2	9.7	392	343	615	1141	86	148
	2003	23.4	9.3	290	280	535	1148	75	131
	SEM	2.03		31.5		67.2		8.75	
	p-values								
	tr	0.03		0.863		0.006		0.001	
	year	< 0.001		0.002		0.493		0.045	
	tr*year	0.002		0.206		0.091		0.199	
2–25 cm	2000	9.1	6.1	99	104	852	1066	83	105
	2001	9.1	6.2	105	107	899	1106	89	98
	2002	11.7	7.1	145	122	945	1263	99	113
	2003	9.9	7.1	97	123	971	1053	97	95
	sem	1.22		11.2		52.7		5.5	
	p-values								
	tr	0.069		0.916		0.006		0.342	
	year	0.054		0.054		0.145		0.025	
	tr*year	0.258		0.117		0.123		0.142	
0–25 cm	2005	9.9	5.8	104	89	930	1136	67	114
	SEM	1.09		7.7		55.8		4.3	
	p-value								
	tr	0.04		0.19		0.04		0.033	

Table 3. Concentrations of P, K, Ca and Mg in herbage DM on grass and grass-clover pastures in 2001–2003. SEM indicates the standard error of mean (n = 4 per treatment, tr), G = grass, GC = grass-clover.

	P (g kg^{-1} DM)		K (g kg^{-1} DM)		Ca (g kg^{-1} DM)		Mg (g kg^{-1} DM)	
	G	GC	G	GC	G	GC	G	GC
2001	3.65	3.20	36.6	32.6	4.00	9.40	1.80	2.20
2002	3.32	3.35	41.7	35.8	3.90	8.90	1.90	2.30
2003	3.70	3.56	41.3	37.8	3.70	11.90	1.70	2.60
SEM	0.052		0.78		0.26		0.05	
p-values								
treatment	0.018		0.003		< 0.001		< 0.001	
year	< 0.001		< 0.001		< 0.001		0.005	

Nutrient leaching and surface runoff

The amounts of leached minerals in the G and CG treatments were nearly equal during grazing years and the sward renewal year (Table 4). P leaching was low. Ca was the main cation in the leachate and the leached amount of Ca increased during the experimental years. The leached amounts of K and Mg were quite similar compared to each other during grazing years. During the third grazing year the amounts of K and Mg leached were two-fold compared to earlier years.

The leached amounts of cations increased markedly during the sward renewal year compared to the grazing years without any differences between the treatments. Leaching of Mg was over 45% higher from the G treatment than from the GC treatment during the whole four-year ley rotation. There was a tendency for greater leaching of Ca from the G than the GC treatment. The amounts of leached K, Ca and Mg (kg^{-1} ha^{-1} y^{-1}) increased linearly with the amount of leachate (mm y^{-1}, R^2 0.98–99) whereas that of P did not.

The P concentration in lysimeter drainage was low throughout the experiment (< 0.06 mg l^{-1}). Highest cation concentration was found in the G treatment, where Ca^{2+} concentrations exceed 30 mg l^{-1} during sward renewal year. There was no difference between the treatments in K^+ concentration during grazing years or renewal year. The Mg^{2+} concentration in G-treatment lysimeter runoff rose significantly during grazing years than that of GC treatment. It also remained high through the sward renewal year.

The structure of the experimental field allowed surface runoff measurements of G treatment only. Approximately 90% of the surface runoff was caused by spring thaw. The nutrient concentrations in surface runoff varied considerably between years (Table 5). Surface-runoff concentrations of K and Mg decreased during grass-cover years, while there was no clear trend in runoff concentrations of Ca or P. Despite this, the amount of P in surface runoff clearly increased during the experimental years. The proportion of PO_4-P was high, comprising 90% of the total P. The peak PO_4-P concentrations, ranging from 3.2 to 4.2 mg l^{-1}, occurred at the beginning of the thaw, but they dropped rapidly to approximately 1 mg l^{-1}. All the nutrient concentrations and amounts in the surface runoff decreased markedly during the sward renewal year.

Table 4. The amounts of leached minerals from grass and grass-clover sward treatments during the grazing years 2001–2004, the renewal year 2004–2005 and the sum of the whole ley rotation 2001 – 2005. SEM indicates the standard error of mean.

Year/treatment	Leachate mm	SEM	Tot P kg ha^{-1}	SEM	K kg ha^{-1}	SEM	Ca kg ha^{-1}	SEM	Mg kg ha^{-1}	SEM
2001 – 2002										
Grass	118	84.1	0.01	0.008	10.0	8.00	25	20.9	9.2	7.29
Grass-Clover	100	65.7	0.01	0.010	7.5	4.73	14	8.1	5.6	3.33
2002–2003										
Grass	116	45.5	0.03	0.013	9.9	5.16	24	13.8	9.5	4.70
Grass-Clover	141	79.8	0.02	0.011	11.3	6.52	20	9.6	7.9	4.10
200 –2004										
Grass	189	24.7	0.01	0.001	17.0	3.91	56	16.2	23.0	4.58
Grass-Clover	204	20.5	0.01	0.001	18.3	3.22	39	5.1	15.0	1.64
p-values										
Treatment	0.63		0.52		0.97		0.44		0.29	
Year	0.1		0.085		0.06		0.001		0.002	
Treatment * year	0.85		0.77		0.82		0.57		0.48	
covariance struc.			ar		cs		cs		cs	
Renewal year 2004–2005										
Grass	330	32.3	0.03	4.0	35.9	6.51	107	18.0	44.2	8.19
Grass-Clover	464	27.7	0.04	5.4	44.2	6.52	76	7.5	30.2	3.14
p-value										
Treatment	0.05		0.005		0.17		0.16		0.16	
Sum 2001–2005										
Grass	753	128.3	0.07		73		213		86	
Grass-Clover	909	164.5	0.08		81		148		59	
p-value										
Treatment	0.05		0.15		0.12		0.12		0.012	

Table 5. Minerals in grass pasture treatments (G) surface runoff water during the grazing years 2001–2004 and the renewal year 2004–2005. SD indicates the standard deviation (n = 2 except 2001–2002 n =1).

	runoff	SD	Tot P	SD	PO_4P	SD	K	SD	Ca	SD	Mg	SD
Concentrations mg l^{-1}												
2001–2002			1.67		1.51		19.6		3.4		1.1	
2002–2003			1.19	0.200	1.09	0.200	13.8	1.98	1.9	0.114	0.8	0.12
2003–2004			1.34	0.060	1.18	0.090	10.7	1.12	2.0	0.321	0.6	0.04
2004–2005			0.88	0.110	0.82	0.110	7.9	1.10	0.6	0.250	0.2	0.08
mm or kg ha^{-1}												
2001–2002	66	-	1.08		0.97		13		2.2		0.7	
2002–2003	99	38	1.14	0.248	1.05	0.215	13	3.3	1.9	0.56	0.7	0.17
2003–2004	107	10	1.43	0.710	1.25	0.021	11	0.2	2.1	0.29	0.6	0.02
2004–2005	85	0,1	0.75	0.088	0.69	0.089	7	0.9	0.5	0.30	0.1	0.07

Nutrient balances

The inputs and outputs of nutrients during grass cover years were almost in balance. Fertilizers and concentrates are the main sources of inputs, deposition is of minor importance. Nearly 60% of the P input in the G treatment came as fertilizer and 40% was in the feeds and concentrates. The proportion of input as fertilizers was even greater for K (at 79%), but only about half of the inputs of Ca and Mg, for these elements inputs from concentrates and minerals were also a large input channel. On average, mineral inputs to the GC treatment were 38% that of the G treatment, because the only input source for GC was that of concentrates. The largest relative difference between G and GC was for K and smallest was for Mg.

The main nutrient outputs were milk, excretion during milking and, with the exception of P, leaching. The major P output from both treatments was milk, which accounted for 57 and 58% of the total P output for G and GC, respectively. For the cations, the proportion of nutrient outputs that were removed in milk was considerably less: 6% for Mg, 18% for K and 26% for Ca. The second largest output for P was the excretion during milking, which accounted 35% of the total P output. Losses of P in surface runoff, however, are also an important factor, even though actual quantities are not large. The proportion for K was even larger: 61% and 57% for G and GC, respectively. For Ca and Mg, leaching was the largest output pathway for both G and GC (Table 6).

Table 6. Average nutrient flows and balances for the grazing years. G = grass, GD= grass-clover swards.

	P		K		Ca		Mg	
Inputs kg ha^{-1}	G	GC	G	GC	G	GC	G	GC
Fertilizers	23	0	89	0	33	0	8	0
Concentrates	16	15	24	22	30	28	10	9
Deposition	0	0	0	0	0	0	0	0
Total input	39	15	112	22	63	28	18	9
Outputs kg ha^{-1}								
Milk	12	11	21	19	17	15	1	1
Excretion during milking	7	7	72	58	10	20	5	6
Retention in pregnancy	0.5	0.5	0.5	0.4	0.7	0.6	0.2	0.2
Surface runoff	1.2	0.9	12	12	2.1	2.1	0.7	0.7
Leaching	0	0	12	12	35	24	14	10
Total output	21	19	118	103	65	62	22	17
Balance kg ha^{-1}	18	-4	-5	-81	-1	-34	-4	-8

Discussion

The high pasture production for both treatments was partly caused by the optimal rotational grazing system. In consequence, the amount of grazing days was 488 or 450 y^{-1} ha^{-1} (equals to stocking rate of 4.4 and 4.0 cows ha^{-1}) in G and GC treatment, respectively, was also high. In continuous grazing system the stocking rate is usually somewhat lower. As the grazing pressure was high, the physical and chemical impacts of grazing may be considered high compared with average Finnish pastures (Virkajärvi 2005). There were substantial differences between volumes and speeds of different mineral flows on this experiment, similar as reported by Owens et al. (2003) and Whitehead (2000). The main emphasis in the discussion is on P due to its importance on environmental pollution.

There was a slight decreasing trend in surface soil pH, especially on the fertilized G treatment. According to Bolan et al. (1991) pasture soil acidification is due to nitrification of ammonium in fertilizer and urine patches (both release H+ ions) and subsequent nitrate leaching (NO_3^- leaching with Ca, Mg and K causes H^+ ion excess in soil). In this experiment the acidification was the similar as that found by Saarela and Vuorinen (2010) on a cut grass soil fertilized with 180–230 kg NO_3-N ha^{-1} y^{-1}.

An additional factor affecting nutrient dynamics in pasture soils is compaction which affects soil water distribution and oxygen availability caused by trampling, water etc. During the grazing years the soil surface (2–15 cm) of the experimental pasture was slightly compacted (measured by penetrometer), the G treatment significantly more than GC treatment (Saarijärvi 2008) and the soil pore structure was damaged (measured by infiltration rate) compared to that of the cut area (Pietola et al. 2005). The distribution of water between surface runoff and leaching remained the same throughout the experiment, and thus trampling probably had no significant effect. After ploughing the soil in spring 2004, infiltration was the major form of water output.

Nutrient inputs

In general the non-nitrogen fertilizer inputs to the G treatments were modest and for the GC treatment there were none. The P input in concentrates was similar as in the P fertilizers. Thus the hot spots for P dynamics are dung pats and the major soluble nutrient immobilization probably occurred under urine patches and dung pats, as is also the case for N (Whitehead 2000, Saarijärvi and Virkajärvi 2009). Over 16 kg P ha^{-1} were cycling within the system during the grazing season, calculations being based on the average P concentration (10.2 g kg^{-1}DM) of the dung and number of dung pats (5090) per hectare (Saarijärvi 2008). This is 46% of the total P input and, as the dung pats cover yearly 4% of the pasture surface area, this cycling was concentrated on only 12% of the whole surface area during the 3 experimental years (excluding the possible overlap of the pats).

There was a steady increase in the surface soil P concentration in the G treatment during grazing years. This was probably caused by P fertilizer, as reported from cut grass (Saarela and Vuorinen 2009). The amount of fertilizer P (applied according to Finnish fertilization recommendations) of 23 kg P ha^{-1} increased the soil ammonium acetate soluble P concentration only 4.7 mg l^{-1} y^{-1}. The rest of the fertilizer P was probably used by plants or adsorbed on short-range-order oxides and Al and Fe oxides, common in weakly developed acidic Finnish soils (Peltovuori 2006, Saarela and Vuorinen 2010). In the GC treatment the surface soil P concentration remained low throughout the experiment.

Even though the G treatment also received Ca, K and Mg in compound fertilizers, the concentrations of these elements in the soil did not rise during the experiment. The opposite occurred in the case of Ca, as concentration decreased in the surface soil in G treatment and increased in the GC treatment. The difference between treatments was statistically significant and the difference remained through the sward renewal year.

The explanation for the increase on the GC treatments of surface soil Ca concentration during the experiment may be the high Ca concentration in clover plants. Clover plants were dominant (40–80% of total DM) in the vegetation (Saarijärvi 2008). It is likely that senescing plant tissues release soluble nutrients thus keeps surface soil Ca concentration high. The Mg concentration in clover was slightly higher than in grass. The change in surface-soil Mg concentration during the experiment was not so evident as that of Ca concentration. There was no difference in soil K concentration between the treatments. The rise in surface soil K concentrations, equal in both treatments, was probably caused by excreted urine (Haynes and Williams 1993) which covered annually 17% of the pasture area excluding the overlaps (Saarijärvi 2008). Stratification was lost during ploughing and the nutrient concentrations returned nearly to the pre-experimental level.

Nutrient outputs

The removal of P in milk (58%) is comparable with Whitehead (2000), who estimated that milk accounted for 67% of the total P output from intensively managed dairy pasture. The total amount of P output and yearly P excess for the G treatment were nearly equal to that of silage production (Saarela and Vuorinen 2010). In Central Finland's light mineral soils most of the P losses occur during snowmelt, and are transported in surface runoff (Turtola and Kemppainen 1998) when cations are lost preferentially by leaching through the soil matrix whenever the soil moisture exceeds field capacity (Owens et al. 2003).

The increasing soil P concentration, or recently applied fertilizer or manure P, can increase the P loss in surface runoff (Kleinman et al. 2002). Surprisingly in this experiment the yearly average PO_4-P concentration of the surface runoff water did not correlate with the soil P concentration as shown by Kleinman et al. (2002) and Pote et al. (1996), respectively). Instead, the total amount of the PO_4-P (kg ha^{-1}) in surface runoff was strongly dependent on soil P concentration (Fig. 1). In spring, the effects of low temperature, low salt and PO_4-P concentration in melting water and high solution to soil ratio may cause desorption of P from the soil (Yli-Halla and Hartikainen 1996). These factors could explain the correlation between the amounts of P in surface runoff and soil P, as the amount of snow-melt water in spring was probably high enough every year to extract most of the soluble P from the soil. As the snow melt water is an effective solvent, P accumulation in soils must be avoided. In addition, soil P can be used as a direct estimate for the amount of surface run off P under similar conditions (soil properties, pasture, snow cover).

The PO_4-P in snowmelt water followed the pattern where P concentration at the beginning of the spring thaw (data not shown) was high and then decreased after the first few days of the runoff period. This phenomenon was also seen in Uhlen (1988) and Uusi-Kämppä and Heinonen-Tanski (2008) who suggested that high P concentration at beginning of the runoff period were caused by the release of P from frozen grass cells during the winter freeze-thaw cycles. On pastures there are also decomposing dung pats that affect the P load (Whitehead 2000). The microbial lyses in surface soil caused by winter circumstances is one likely source for P in surface runoff (Jeffries et al. 2010). As expected, the easily soluble P in surface soil, measured as soil P (aac), decreased almost to the level before the experiment when ploughed in spring 2004, and this was reflected in decreased amount of P in the surface runoff during the renewal year. This is in line with studies of Peltovuori (2002) and Sharpley (2003), where the diluting effect of low P soil (subsoil) mixed with high P soil (topsoil) was almost linear.

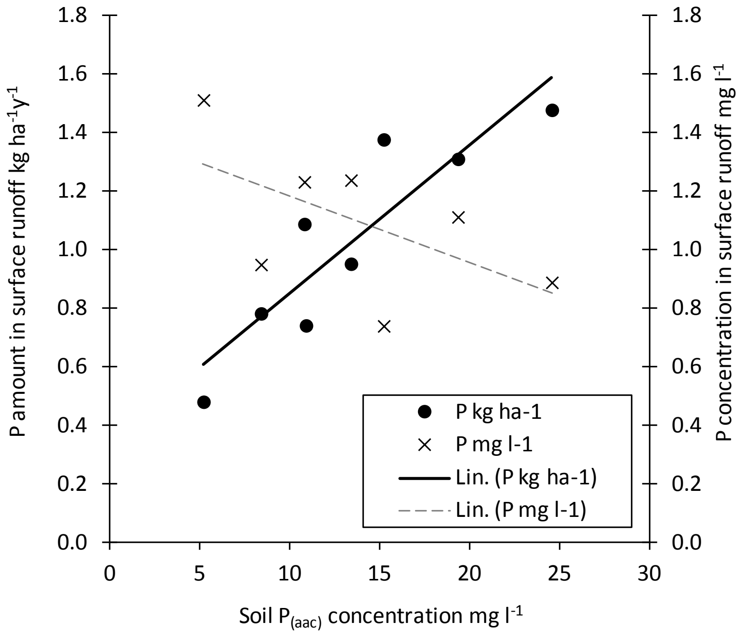

Fig. 1. Soil P concentration correlation to runoff total P concentration and runoff total P amount during the experiment, 2001–2005. Each data point represents the result from a single runoff plot for one hydrological year. The equation for soil P and P amount in runoff is y = 0.0506x + 0.3443, R^2=0.81. The equation for soil P and P concentration in runoff is y = -0.0226x + 1.4093, R^2=0.33.

High total P and PO_4-P loads in surface runoff water have been measured from grass leys with surface-applied artificial fertilizers or organic residues, and intensively managed pastures (Turtola and Yli-Halla 1999, Kleinman et al. 2002, Uusi-Kämppä and Heinonen-Tanski 2008). In our experiment, the amounts were comparable to those given by Turtola and Kemppainen (1998) for slurry or mineral fertilizer applied in May (1.40 and 1.32 kg P ha^{-1}, respectively). However, the total P load from pasture was much smaller than in Uusi-Kämppä and Heinonen-Tanski (2008) and Turtola and Kemppainen (1998), who measured high P loads from from cut grass ley that received slurry in autumn (2.7 and 4.2 kg total P ha^{-1}, respectively).

On average, the proportion of the PO_4-P of the total P was as high as 91%. This is clearly higher than the proportions reported by Turtola and Kemppainen (1998), Kleinman et al. (2002) or Uusi-Kämppä and Heinonen-Tanski (2008). Thus, based on the amount and the form of P in the surface runoff, intensively managed pastures appear to have a high potential for eutrophication of P-limited Finnish surface waters (Arvola et al. 2011) as the PO_4-P is readily used by algae.

The surface runoff accounted for 6% of the total P output. In this experiment the mean P excess was 22.1 kg ha^{-1} y^{-1}, of which only 7% could be seen as an increase in the soil soluble P fraction and 13% was lost in surface runoff. The incidental losses of P were minimal, as most of the surface runoff (84%) was generated during spring months. As typical for this soil, leaching of P was negligible (Saarijärvi et al. 2004). This further supports the findings of (Uhlen 1988) and indicates that the P balance alone does not provide a good estimate of the amount of runoff P within an area, but land use and surface soil P concentration should be considered when forming an estimate.

The nutrient outputs in milk were 26%, 18% and 6 % of the total output values for Ca, K and Mg, respectively. Unlike the P output in milk, these figures are less comparable to the estimates of Whitehead (2000), which were 7%, 26% and 2% for Ca, K and Mg, and respectively. For Ca and Mg, however, leaching was the main form of output and comprised 58% and 78% of the total output for these elements, whereas the proportion of the output of K lost by excretion during milking was 55% of the total removal.

The amounts of leached cations were lower than the amounts presented by Steele et al. (1984) but comparable to values reported by Owens et al. (1998, 2003). The molar equivalent cation concentrations in leachate correlated strongly (data not shown) with molar equivalent nitrate concentration as expected (Steele et al. 1984). Very high amounts of K can be lost through leaching from sandy soils (Yläranta et al. 1996, Whitehead 2000), but here the losses through leaching and surface runoff were equal and rather modest.

Greatest differences between temperate long term pastures and boreal short term pastures are impacts of spring snow melt period on nutrient leaching and regular renovation of the sward. Mixing of soil changes the soil structure, destroys the stratification of nutrients and releases nutrients compared to stabile soil conditions as seen in results. In addition, mixing the soil and destroying the vegetation increases the risk of erosion. However, the dairy production in Finland is located mostly on coarse mineral soil areas this does not cause a serious thread in for erosion (Saarijärvi 2008).

Nutrient balances

According to Whitehead (2000), leaching, milk and excretal outputs may cause net losses of minerals from the pasture area and this may lead to negative nutrient balances. In the present study this was the case for the unfertilized GC treatment but not for the fertilized G treatment. In Finland the nutrient balances on fertilized pastures are usually positive, rather than negative, as the fertilizer recommendations for pasture are almost equal to amounts present in the herbage of cut swards, and the amounts of removal of nutrients in milk and excretion during milking are less than in grass harvested by cutting.

The negative balances on the GC sward did not affect soil nutrient concentrations. It is apparent that the soil nutrient status was sufficient to compensate for a small amount of net removal of nutrients from the area during the short (3 year) pasture period. Thus, it seems that clover pasture with adequate soil nutrient status does not need fertilizer amendments during grazing years. The dry matter yield of the removal year was also equal for both sward treatments, which further supports this conclusion. Straight comparisons between boreal short term and temperate long term dairy pastures on nutrient dynamics is difficult, as the studies measuring non-nitrogenous nutrient budgets are rare (e.g. Whitehead 2000).

Conclusions

Even though the amounts of nutrient inputs to the systems were clearly different in the G treatment, which can receive 2–5 times more nutrients than the GC treatment, the outputs were quite similar. The largest output pool for Ca and Mg was that by leaching, for P it was via the milk, and for K it was excretion during milking in both treatments. It is important to include the excretion during milking in balances calculated from dairy pastures. For both sward treatments all the nutrient balances were negative except the P balance in the G treatment, which was highly positive.

In the G treatment, the surface soil P concentration increased linearly though the grazing years and the P amount in the surface runoff increased equally. Even though the total amount of P lost in surface runoff was comparable to amounts in average agricultural runoff, 90% of the lost P was in soluble form that is readily used by algae. This gives a reason to re-evaluate the pasture P fertilization recommendations.

The nutrient concentrations in soil of the GC treatment changed less than on the G treatment. It seems that in short-term ley farming, grass-clover swards can retain nutrients in the soil better than pure grass swards.

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