N, P and K budgets for crop rotations on nine organic farms in the UK

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Abstract. Nitrogen (N), phosphorus (P) and potassium (K) budgets were calculated for 9 organic farms in the UK. The farms were on sandy loam, silty clay loam and silty loam over chalk with stockless farming systems and cattle, pig and poultry enterprises with a significant proportion of arable cropping. A soil surface nutrient budget was calculated for the target rotation on each farm using information about field management and measurements of the soil, crops and manure. Losses of N through leaching and volatilization were calculated independently using the NITCAT and MANNER models.

Nutrient budgets for seven of the farm rotations showed an N surplus, six a P surplus and three a K surplus. The ratio of N inputs supplied in the form of biological fixation : manure : atmospheric deposition was approximately 2:2:1 for stocked systems and 2:0:1 for stockless systems. Phosphorus surpluses resulted from supplementary P fertilizer (rock phosphate) and additional feed for non-ruminant livestock. The stockless system without P fertilizer resulted in a large P deficit and stocked systems, which relied on recycling manure alone, a small P deficit. Only rotations with a large return of manure or imported feed showed a K surplus or a balanced K budget.

Keywords: nutrient budgets, organic farms, rotations, sustainability

INTRODUCTION

Crop rotations are a lynch-pin of organic farming systems, both for the management of nutrients and soil fertility and the control of pests, diseases and weeds (Stockdale *et al*. 2001). The crop rotation is therefore an appropriate level to evaluate organic farming systems both to aid improvements in farm management and profitability, and also to minimise environmental impact.

Nutrient budgets have been used widely in a range of farming systems at different scales (Scoones & Toulmin 1998) to assess nutrient use efficiency, long-term sustainability and environmental impact of farming systems. Fortune *et al.* (2001) used simple nutrient budgeting approaches at the farm scale to suggest that organic farming systems have the potential to maintain soil fertility and to minimise losses. The principle aim of this study was to compile N budgets for typical ley/arable rotations on organic farms in the UK. Data were also collected to calculate P and K budgets in order to make a simple assessment of the sustainability of organic farming systems in the UK.

METHODS

Sites

Nine organic farms in the UK, which had been fully certified for more than 5 years, and which had a significant proportion of arable cropping in the rotation were chosen (Table 1). The soil types included sandy loam, silty clay loam and shallow silty loam over chalk. The predominant stock used on the farms were dairy cattle (Farms 1 & 3), beef cattle (2 & 9), outdoor pigs (4 & 6) and poultry (7), and two additional farms were stockless (5 & 8). The target rotation for each farm was identified with the farm manager, although this rotation was not necessarily adhered to across the whole farm in every season. For each farm, a set of fields was chosen to represent each phase of the rotation in the year of sampling, 1998-1999. Field management information for this and a number of previous seasons was compiled through interviews with the farm manager and from documented farm records. Between two and five years of management information was collected for each field (Table 2).

System definition and approach used to calculate nutrient budgets

A nutrient budget was calculated for each field. The system was defined as the cropped area to the maximum rooting depth (Figure 1). This type of budget is sometimes known as a soil surface budget. Nutrient inputs were from N fixation, atmospheric deposition, rock phosphate, manure and seed. Nutrient outputs were through offtake in crop and animal products, volatilization and leaching. Livestock interacted with the system through returns in manure (including both applied manure and excreta returned during grazing) and through nutrient offtake in the form of milk and growth during grazing. Outdoor pigs interacted with the system less than ruminant livestock because they relied on imported feeds. Their net contribution of nutrients to the soil was through excreta. For this reason the nutrient offtakes in animal products were not calculated for outdoor pigs.

Nutrient budgets were thus compiled for each field for each of the two to five years of available information. The two to five year budgets calculated for each phase of a rotation were then averaged and the final rotational budget was the average of all the rotational phases, calculated on a per hectare basis.

Quantification of inputs and outputs

N fixation by leguminous crops, free-living bacteria and nutrient inputs through atmospheric deposition were estimated using data from the literature (Table 3). Samples of manure and any other composted waste materials were collected on most of the farms, taking care to obtain representative samples (Table 2). Total N was determined on fresh samples by wet oxidation (Kjeldahl method) to avoid N losses by volatilization during drying. Nitrogen inputs in manure and composts were calculated, therefore, from the measured N contents and application rates. For P and K and in the few cases where the N content had not been measured, estimated nutrient contents were used (Table 3). Excretion by outdoor pigs was estimated using the number of animals, age, duration in a field and the amount and type of feed (Smith *et al*. 2000). The feed conversion figures determined for conventionally managed pigs were reduced by 20% to account for their extra maintenance requirements. This resulted in more manure N being produced for the amount of feed N consumed compared with conventionally managed pigs. Nutrient inputs in seed were estimated from drilling rates and literature nutrient content.

Crop samples were taken from 18 fields in cereals at the 1999 harvest. Samples were dried and ground before analysis for total N concentration by combustion (Leco CN analyser). The nutrient offtake in these crops was calculated from the yield and its measured N content. For P and K, and crops for which measurements of N concentration were not made, data given in Table 3 were used. Estimates of the amount of N exported by cattle during the grazing period as saleable produce (milk and meat) or lost by volatilization during grazing were based on work done on conventional farms (Jarvis 1993; Scholefield 1991; Sommer & Hutchings 1997; Table 3). The amount of N lost due to leaching was calculated using the NITCAT model (Lord 1992). This model estimates the amount of potentially leachable N based on the previous crop, modified according to the balance between N inputs and offtakes. The resulting potential leaching load is further modified according to N inputs in the autumn, mineralization of N residues from previous years and autumn N uptake. The actual amount of N that leached depended on the amount of drainage, which was estimated using IRRIGUIDE (Bailey & Spackman 1996) from inputs of soil type, crop cover and weather. The MANNER model (Chambers *et al*. 1999) was used to calculate the amount of manure N volatilized as ammonia after application. This depended upon the amount of available N in the manure, how quickly it was incorporated after application and, for slurry, whether or not it was injected. The amount of available N in the manure was either measured or a standard value for organically produced manures was assumed (Table 3).

Soil samples were taken from each field to a depth of 90 cm or to the bed rock. The samples were refrigerated and analysed for total N, NH_4-N and NO_3-N. A soil bulk density of 1.3 g cm^{-3} was assumed to convert the percentage N in the soil to kg N ha^{-1}.

RESULTS & DISCUSSION

Nitrogen

The N budgets on seven of the nine farms showed positive budgets (18 to 64 kg N ha^{-1} $year^{-1}$), and two showed negative budgets (-15 and -19 kg N ha^{-1} $year^{-1}$) (Table 4). In the few other N budget studies that have estimated budgets in organic rotations, these have ranged from –38 to 30 kg N ha^{-1} $year^{-1}$ (Nolte & Werner 1994; Kaffka & Koepf 1989). The surplus/deficit of N indicates the impact of that particular farm management on the long-term accumulation or depletion of soil N. The data in this study indicates that on seven of the nine farms the rotations are probably sustainable in terms of N and may even build up soil N in the short-term. Soils on the farms that had been converted for 10 or more years contained 15 to 17 t ha^{-1} of total N (to bed rock or 90cm depth). On farms 8 and 9, where the N budgets were negative, the rotations containing grain legumes were followed by one or two cereal crops. Harvested grain legumes frequently leave an N residue equivalent to only about 25 kg ha^{-1} to a following crop (Table 3). Thus in a rotation with grain legumes followed by cereals, the cereals would have to rely on N supplied by mineralization of soil organic matter and residues of recently added crops and manures. Wheat yields on Farms 8 and 9 provide some evidence for this; the mean wheat yield dropped from 6.0 t ha^{-1} after a forage legume to only 3.8 t ha^{-1} after a grain legume. The total soil N measured in the field of Farm 9, which was converted for more than 10 years, was 12 t ha^{-1}, compared with 15 to 17 t ha^{-1} for the fields sampled on farms with a positive N budget. This suggests that a grain legume-cereal rotation is exploitative of soil N. It should be noted however, that the N budgets estimated for the two rotations with the most positive and negative N balances would have to continue for 30-40 years to produce a 3 t ha^{-1} difference in total N.

The stocked organic systems relied on biological fixation for 42% (range of 35 to 46%) of their N inputs, with manure accounting for 35% (26 to 45%); in these studies the remainder of N inputs was made up by estimates of atmospheric deposition, 22% (13 to 26%). Stockless systems relied on biological fixation (70%) for their N inputs, with the remainder estimated to come from atmospheric deposition (27%). While biological fixation of N is the driving force of the rotational N cycle on organic farms, as might have been expected, atmospheric deposition of N is currently a key source of N in both stockless and stocked systems. Goulding *et al.* (2000) also estimated that atmospheric depositions make an important contribution to the N inputs on organic farms, accounting for 13% of the N inputs in lowland systems and 59% in upland systems. The mean N input for each crop that was removed from the field, e.g. cereals, grain legumes and silage, ranged from 150 to 300 kg N ha^{-1}. This is similar to the amounts of N supplied to non-leguminous crops in conventional systems (MAFF, 2000). However, unlike conventional systems where much of the N is applied as readily plant available nitrate, not all of this N input would be available for plant use because it is incorporated in plant residues and manures. Factors controlling the supply of available N in organic systems are discussed by Berry *et al.* (2002).

N outputs resulted mainly from crop offtake and leaching. However, the size of these two outputs was heavily influenced by the intensity of animal production and soil type. For the stockless farms (5 and 8), the low intensity animal production systems with beef (2, 9) and the sparsely stocked outdoor pigs (6), the average N input was 155 kg ha^{-1} $year^{-1}$ and the average N output was 141 kg ha^{-1} $year^{-1}$. The higher intensity animal systems, which included the dairy systems (1,3), the densely stocked outdoor pigs (4) and the poultry (7), had an average N input of 191 kg ha^{-1} $year^{-1}$ and an average N output of 155 kg ha^{-1} $year^{-1}$. The low intensity systems had a greater proportion of their N outputs as crop offtake (average 59%) compared with leaching (31%) and volatilization (3%) (volatilization could amount to 10% where manure was not incorporated quickly). The high intensity animal systems had a greater proportion of their N output as leaching (41%) compared with crop offtake (31%). Predictably, outputs as animal products and volatilization were greater in the high intensity systems than in the low intensity systems. It appears, therefore that, in these organic systems, efforts to increase animal production resulted in quantitatively and proportionately more N being wasted through leaching and volatilization. This might be expected because the process of converting atmospheric N to animal products via numerous cycles of forage plant growth, grazing and excretion is inefficient. However, this is difficult to demonstrate conclusively with these farm studies because the high intensity systems were also generally on soil types more at risk of leaching.

In absolute terms, the largest source of error within the N budgets was from estimates of biological fixation. The range of biological fixation was reviewed by Watson *et al.* (2002); they concluded that a 1 to 2 year old white clover ley could fix 50% more or less N than that assumed in Table 3. This variability is so large that it highlights the need to develop more precise methods of quantifying the effects of legume species, soil pH, soil available N etc. on N fixation. Estimates of the amount of N added in manures are often a large source of error in N budgets, but this was minimised in this study through measurement. NITCAT was developed to estimate leaching under conventionally managed systems, but was able to accommodate organic systems because it had been based on data from experiments without inorganic N fertilizer and measured values of soil organic matter were used for estimating rates of mineralization. Nitrous oxide losses from the soil were not estimated for these N budgets because they have been shown to be negligible in grassland when applications of inorganic fertilizer were less than 100 kg N ha^{-1} (Scholefield *et al.* 1991) and to only amount to losses of between 1 and 3 kg N ha^{-1} year^{-1} in conventionally managed arable systems (Webb *et al.* 2000). Volatilization losses of N from cut and mulched grass clover ley were found to be only 0.2 kg ha^{-1} year^{-1} by Schmidt *et al*. (1999) and were therefore assumed to be negligible in these budgets.

This study has shown that N budgets should be calculated using crop N contents of produce from organic farms rather than conventional farms, e.g. the average N content of conventionally produced wheat, barley, oats and potatoes (Alderman & Cottrill, 1995) was about 20% greater than in organic crop produce (data from this study and W. Cormack *pers. comm.*).

Phosphorus

The P budgets on 6 of the farms showed a positive budget (6 to 34 kg P ha^{-1} year^{-1}) while 3 had negative budgets (-1 to –8 kg P ha^{-1} year^{-1}). Other farm scale budgets have measured a similar range of P budgets, -1 to 23 kg ha^{-1} year^{-1}, (Hermansten & Kristensen 1998; Cuttle & Bowling 1999). Because P flows in rotational systems are quantitatively much smaller than those of N (average outputs of 14 kg P ha $^{-1}$ year^{-1} in this study), the small deficits reported here, if widely applicable, may have a significant impact on the sustainability of such organic systems even in the medium term. However, in most cases the use of supplementary P fertilizer in the form of rock phosphate (on 5 farms), corrected any potential P deficit. The large P surplus (34 kg P ha^{-1} year^{-1}) on Farm 1 would be removed if the supplementary P fertilizer (33 kg P ha^{-1} year^{-1}) currently used was withdrawn. On Farms 4 and 7 the use of supplementary feed for the non-ruminant livestock contributed to the P surpluses of 26 and 7 kg ha^{-1} year^{-1} respectively. This has been inferred from the manure returns because imported feed was not accounted for directly in these P budgets. Whether or not release of P from soil reserves is sufficient to match any net export of P within a rotation depends upon soil type and past P manuring before conversion to organic husbandry. The available P content in the upper 5cm of a sandy soil in the Netherlands under a silaged grass/clover ley fell by 25% over 5 years, even when manure was applied (Younie & Baars 1997). However on a non-sandy soil, an annual P deficit of 2 to 4 kg P ha^{-1} caused no decline in the content of extractable P over 10 years (Kaffka & Koepf, 1989).

Potassium

None of the rotations received any supplementary K fertilizer, though the inputs of rock phosphate contained small amounts of K (Table 4). The K budgets on 3 of the farms showed a positive budget of 9 to 28 kg K ha^{-1} $year^{-1}$, one was perfectly balanced (Farm 7) and on 5 farms there was a negative K budget of -21 to –52 kg ha^{-1} $year^{-1}$. On Farms 1, 3 and 4 there were substantial inputs of manure to the fields being studied and this returned more K than was removed. This occurred because the livestock on these farms were fed with imported concentrates. On the other livestock farms, inputs of K via manure were not sufficient to balance the removal in silage and other crops, except Farm 7. Potassium leaching from the manure heaps was not estimated for farms 1, 2, 3, 7 and 9 because either standard values for composted manures were used or measurements of the manure were made several months before the manure was applied to the land. Leaching from manure heaps may represent a significant loss of K from the system. Godden & Penninckx (1997) reported values from a number of studies showing losses during composting from 18 to 67% of the original K content. On the two farms without stock there were large negative K budgets of up to –52 kg ha^{-1} $year^{-1}$. Other studies have shown that livestock only farm budgets are often positive for K (e.g. Cuttle & Bowling 1999), with mixed farms more likely to have negative budgets (Nolte & Werner 1994). Askegaard and Eriksen (2002) showed that the K budget of a mixed system changed from negative to positive as the stocking rate increased because K returns as manure increased. As with P, the ability of any deficits to be compensated through release from soil reserves depends upon soil type and past manuring before organic conversion. Some soils in the UK can supply up to 40 kg K ha^{-1} $year^{-1}$ (Goulding & Loveland 1990). However, the extractable K content of sandy soils has been shown to decrease by 62% within 3 years under a silaged grass/clover ley (Younie & Baars 1997). In general, K deficits of greater than 25 kg K ha^{-1} $year^{-1}$ in any rotation should be a matter of concern (particularly on farms 8 and 9) and soil K index should be carefully monitored, so that depletion of soil reserves can be prevented.

CONCLUSIONS

Of the nine farms studied here, seven had a positive N budget, six had a positive P budget and three had a positive K budget. The degree to which a particular nutrient was in surplus or deficit appeared to be independent of the budgets of the other nutrients within the rotation. The ratio of N inputs supplied in the form of biological fixation : manure : atmospheric deposition was approximately 2:2:1 for stocked systems and 2:0:1 for stockless systems. This emphasises the importance of the N supplied by atmospheric deposition and indicates that policies to reduce N emissions to the atmosphere could have a major impact on N budgets for organic systems. Applications of rock phosphate and additional feed for non-ruminant livestock caused the surplus P budget on the farms with livestock. Stockless systems without rock phosphate had a large P deficit and stocked systems which relied only on recycling manure had a small P deficit. Only farms with large manure returns from stock fed with bought-in feed had a positive or neutral K budget. The surplus would have been less for the cattle farms and the poultry farm if there had been K leaching from manure heaps and this had been estimated. The productivity of the rotations in P or K deficit will depend on the ability of the soil to supply these elements by weathering of native soil P and K or from reserves accumulated before conversion to organic systems.

The budgets calculated for these case studies indicate that there is no reason why organic farms should be inherently unsustainable with regard to N. However, it is clear that the farms are reliant on importing animal feeds, rock phosphate or other supplementary nutrients to achieve a balanced budget for P and K. The wide differences in the nutrient budgets arise from the contrasting rotations, the intensity of livestock production and the use of supplementary nutrients. Similar data have been obtained in studies of nutrient budgets in other organic farming systems (e.g. Kaffka & Koepf 1989; Cuttle and Bowling 1999; Nolte & Werner 1994; Watson *et al.* 2002). The data presented here suggests that there is scope for individual organic farms to increase the efficiency with which they use nutrients within the rotation to minimise losses to the environment.

Simple rotational budgets, as used in these case studies, are one tool to enable an increased understanding of nutrient flows at a rotational level by farmers and their advisors. This type of budget should be considered for complete rotations, and in conditions which represent the typical range of management practices and yields for the farming system. While rotational budgets can represent the whole farm nutrient budget for stockless systems, in mixed systems additional consideration of the entire nutrient flows across the farm gate may be critical, especially where budgets are used to propose management changes. In addition temporal flows of nutrients between rotation phases are also important: N is fixed and P and K inputs are often made to the ley phase of the rotation, and then released in plant available forms throughout the whole rotation. Average N, P and K budgets for the rotation as a whole may also mask important differences between fields.

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Table 1 Basic farm information and the crop sequence in the target rotation at each farm.

Farm number	Soil type	Livestock enterprise	Rotation
1	SZL	Dairy	Ley, Ley, Ley, Beet, SB, WT
2	ZCL	Beef	Ley, Ley, Ley, WW, WT
3	SL	Dairy	Ley, Ley, Ley, WW, WT
4	caZL	Pigs/ sheep	Ley, Ley, WW, SC, Pigs, WW
5	ZCL	None	RC, WW, SB, SC
6	ZCL	Pigs	Ley, Ley (pigs), WW, SW, WC
7	SL	Chickens	Ley, Ley, WW, WO, WB, WW, SBa
8	ZCL	None	RC, Pots, WW, SB, SW
9	caZL	Beef/ sheep	Ley, Ley, Ley, WW, WO, WB, WW, SO

Soil types: ca – calcareous; C – clay; L – loam; S – sand; Z – silt.

Crops: Beet – fodder beet; Ley – white clover / ryegrass ley; Pigs – pigs on stubble; RC – Red clover; SB – spring beans; SBa – spring barley; SC – spring cereal; SO – spring oats; SW – spring wheat; WB – winter beans; WC – winter cereal; WO – winter Oats; WW – winter wheat; WT – winter triticale.

Table 2. Summary of the field management information collected at each farm.

Farm number	1	2	3	4	5	6	7	8	9
Years of data	3	2	4	5	2	2	2	5	2
Cultivation dates	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sowing dates	✓	✓	✓	✓	✓	✓	✓	✓	✓
Seed rates	✓	✓	✓	✓	✓	✓	*	✓	✓
Cultivar	✓	✓	✓	✓	✓	✓	✓	✓	✓
Over winter cover (%)	*	*	*	*	*	*	*	✓	*
Proportion of clover	*	*	*	*	N/A	*	*	N/A	*
Saleable crop yield	✓	✓	✓	✓	✓	✓	✓	✓	✓
Saleable crop N content	*	*	✓	✓	✓	✓	✓	✓	✓
Stocking rates	✓	✓	✓	✓	N/A	✓	✓	N/A	✓
On farm feed & N content	N/A	N/A	N/A	✓	N/A	✓	✓	N/A	N/A
Manure N analysis	✓	*	✓	✓	N/A	✓	*	N/A	✓
Manure information	✓	✓	✓	N/A	N/A	✓	✓	N/A	✓

✓ Exact information obtained
* Estimates made from observation or other information
N/A Not applicable

Table 3. Assumptions used to calculate inputs and outputs of nutrient budgets

Input/output	N	P	K	Source
N fixation (kg element ha^{-1} yr^{-1})				
1–2 year old white clover ley (*Trifolium repens*)	150	-	-	Kristensen *et al.* (1995)
>2 year old white clover ley	85	-	-	Kristensen *et al.* (1995)
Red clover (*Trifolium pratense*)	240	-	-	Schmidt *et al.* (1999)
Spring/winter beans (*Vicia faba*)	200	-	-	Kopke (1987),
Spring/winter bean residue after grain harvest	25			Sylvester-Bradley & Cross (1991)
Free living soil bacteria	5	-	-	Goulding (1990)
Atmospheric deposition (kg element ha^{-1} yr^{-1})				
Close to urban areas	40	~0.5	-	Goulding *et al*. (1998a,b)
Rural areas	30	~0	-	Goulding *et al*. (1998a,b)
Areas unaffected by sea spray			~3	NEGTAP, 2001
Manures				
Cattle FYM (kg element t^{-1} fwt)	5.2	1.1	5.5	Shepherd *et al*. (1999)
Cattle slurry (kg element m^{-3})	2.5	0.42	2.1	Shepherd *et al.* (1999)
Poultry (layer) manure (kg element t^{-1} fwt)	16	4.5	6.0	Anon. (2000)
Crop nutrient content (% element of dwt)				
Wheat (*Triticum aestivum*) grain	1.7	0.3	0.5	OF0178
Wheat straw	0.46	0.1	0.8	OF0145
Spring/winter beans	3.4	0.5	1.0	OF0145
Barley (*Hordeum vulgare*) grain	1.3	0.3	0.5	OF0178
Oat (*Avena sativa*) grain	1.6	0.3	0.5	OF0178
Triticale (*Tritiosecale*) grain	1.5	0.4	0.5	OF0178
Triticale whole crop silage	1.6	0.3	2.0	Alderman & Cottrill (1995)
Grass/clover silage	2.7	0.3	2.1	Alderman & Cottrill (1995)
Fodder beet (*Beta vulgaris*)	1.0	0.1	0.6	Alderman & Cottrill (1995)
Potatoes (*Solanum tuberosum*)	1.4	0.1	0.6	OF0145
Livestock (kg element ha^{-1} yr^{-1})				
Milk offtake during grazing	19	3.0	5.5	Jarvis (1993)
Cattle growth during grazing	14	4.1	1.0	Jarvis (1993)
Cattle gaseous losses during grazing	11	-	-	Scholefield (1991), Sommer & Hutchings (1997)

1 OF0178 – mean of measurements taken in DEFRA project No OF0178, OF0145 - mean of measurements taken in DEFRA project No OF0145

Table 4. Average N, P and K budgets (kg ha^{-1} year^{-1}) for nine case study farms calculated for a complete rotation. The assumptions used for the quantification of inputs and outputs are described in the text.

Farm/rotation	1			2			3			4			5			6			7			8			9		
Stock	DAIRY			BEEF			DAIRY			PIGS			NONE			PIGS			POULTRY			NONE			BEEF		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Inputs																											
Biological Fixation	98			81			77			73			110			60			71			76			73		
Manure	94	19	96	67	8	39	55	9	58	96	31	43				59	14	29	41	18	37				42	8	43
Deposition	30	0	3	40	0.5	3	40	0.5	3	40	0.5	3	40	0.5	3	40	0.5	3	40	0.5	3	30	0	3	40	0.5	3
Seed	2	0.5	1	2	0.5	0.5	2	0.5	0.5	2	0.5	0.5	3	0.5	1	2	0.5	1	4	1	1	5	2	4	3	0.5	1
Rock phosphate		33	0.5		12	0		0	0		0	0		0	0		7	0		0	0		14	0.5		16	0.5
Outputs																											
Crop offtake	47	17	85	84	13	64	63	11	51	33	6	19	76	9	25	77	15	60	81	12	41	88	17	60	113	18	82
Animal offtake	15	2	2	6	2	0.5	11	2	2										2	0.5	0				3	1	0.5
Leaching	75			39			59			136			49			49			50			38			58		
Volatilization	23			11			10			13			0			12			5						3		
Balance	**64**	**34**	**14**	**50**	**6**	**-22**	**31**	**-3**	**9**	**29**	**26**	**28**	**28**	**-8**	**-21**	**23**	**7**	**-26**	**18**	**7**	**0**	**-15**	**-1**	**-52**	**-19**	**6**	**-35**

Figure 1. Conceptual system showing the inputs and outputs of nutrients (N, P & K) used for the calculation of nutrient budgets of a rotation. The livestock interact with the rotation through the returns of manure and by utilisation of the pasture.