1   **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

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1 farming systems both to aid improvements in farm management and profitability, and

2 also to minimise environmental impact.

3

4 Nutrient budgets have been used widely in a range of farming systems at different

5 scales (Scoones & Toulmin 1998) to assess nutrient use efficiency, long-term

6 sustainability and environmental impact of farming systems. Fortune *et al.* (2001)

7 used simple nutrient budgeting approaches at the farm scale to suggest that organic

8 farming systems have the potential to maintain soil fertility and to minimise losses.

9 The principle aim of this study was to compile N budgets for typical ley/arable

10 rotations on organic farms in the UK. Data were also collected to calculate P and K

11 budgets in order to make a simple assessment of the sustainability of organic farming

12 systems in the UK.

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14

15 **METHODS**

16 *Sites*

17 Nine organic farms in the UK, which had been fully certified for more than 5 years,

18 and which had a significant proportion of arable cropping in the rotation were chosen

19 (Table 1). The soil types included sandy loam, silty clay loam and shallow silty loam

20 over chalk. The predominant stock used on the farms were dairy cattle (Farms 1 & 3),

21 beef cattle (2 & 9), outdoor pigs (4 & 6) and poultry (7), and two additional farms

22 were stockless (5 & 8). The target rotation for each farm was identified with the farm

23 manager, although this rotation was not necessarily adhered to across the whole farm

24 in every season. For each farm, a set of fields was chosen to represent each phase of

25 the rotation in the year of sampling, 1998-1999. Field management information for

1   this and a number of previous seasons was compiled through interviews with the farm

2   manager and from documented farm records. Between two and five years of

3   management information was collected for each field (Table 2).

4

5   *System definition and approach used to calculate nutrient budgets*

6   A nutrient budget was calculated for each field. The system was defined as the

7   cropped area to the maximum rooting depth (Figure 1). This type of budget is

8   sometimes known as a soil surface budget. Nutrient inputs were from N fixation,

9   atmospheric deposition, rock phosphate, manure and seed. Nutrient outputs were

10   through offtake in crop and animal products, volatilization and leaching. Livestock

11   interacted with the system through returns in manure (including both applied manure

12   and excreta returned during grazing) and through nutrient offtake in the form of milk

13   and growth during grazing. Outdoor pigs interacted with the system less than

14   ruminant livestock because they relied on imported feeds. Their net contribution of

15   nutrients to the soil was through excreta. For this reason the nutrient offtakes in

16   animal products were not calculated for outdoor pigs.

17   Nutrient budgets were thus compiled for each field for each of the two to five

18   years of available information. The two to five year budgets calculated for each phase

19   of a rotation were then averaged and the final rotational budget was the average of all

20   the rotational phases, calculated on a per hectare basis.

21

22   *Quantification of inputs and outputs*

23   N fixation by leguminous crops, free-living bacteria and nutrient inputs through

24   atmospheric deposition were estimated using data from the literature (Table 3).

25   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

1   actual amount of N that leached depended on the amount of drainage, which was

2   estimated using IRRIGUIDE (Bailey & Spackman 1996) from inputs of soil type,

3   crop cover and weather. The MANNER model (Chambers *et al*. 1999) was used to

4   calculate the amount of manure N volatilized as ammonia after application. This

5   depended upon the amount of available N in the manure, how quickly it was

6   incorporated after application and, for slurry, whether or not it was injected. The

7   amount of available N in the manure was either measured or a standard value for

8   organically produced manures was assumed (Table 3).

9

10   Soil samples were taken from each field to a depth of 90 cm or to the bed rock.

11   The samples were refrigerated and analysed for total N, NH_4-N and NO_3-N. A soil

12   bulk density of 1.3 g cm^{-3} was assumed to convert the percentage N in the soil to kg N

13   ha^{-1}.

14

15   **RESULTS & DISCUSSION**

16   *Nitrogen*

17   The N budgets on seven of the nine farms showed positive budgets (18 to 64 kg N ha^{-}

18   ^{1} $year^{-1}$), and two showed negative budgets (-15 and -19 kg N ha^{-1} $year^{-1}$) (Table 4). In

19   the few other N budget studies that have estimated budgets in organic rotations, these

20   have ranged from –38 to 30 kg N ha^{-1} $year^{-1}$ (Nolte & Werner 1994; Kaffka & Koepf

21   1989). The surplus/deficit of N indicates the impact of that particular farm

22   management on the long-term accumulation or depletion of soil N. The data in this

23   study indicates that on seven of the nine farms the rotations are probably sustainable

24   in terms of N and may even build up soil N in the short-term. Soils on the farms that

25   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

1 upland systems. The mean N input for each crop that was removed from the field, e.g.

2 cereals, grain legumes and silage, ranged from 150 to 300 kg N ha^{-1}. This is similar to

3 the amounts of N supplied to non-leguminous crops in conventional systems (MAFF,

4 2000). However, unlike conventional systems where much of the N is applied as

5 readily plant available nitrate, not all of this N input would be available for plant use

6 because it is incorporated in plant residues and manures. Factors controlling the

7 supply of available N in organic systems are discussed by Berry *et al.* (2002).

8

9   N outputs resulted mainly from crop offtake and leaching. However, the size of

10 these two outputs was heavily influenced by the intensity of animal production and

11 soil type. For the stockless farms (5 and 8), the low intensity animal production

12 systems with beef (2, 9) and the sparsely stocked outdoor pigs (6), the average N

13 input was 155 kg ha^{-1} year^{-1} and the average N output was 141 kg ha^{-1} year^{-1}. The

14 higher intensity animal systems, which included the dairy systems (1,3), the densely

15 stocked outdoor pigs (4) and the poultry (7), had an average N input of 191 kg ha^{-1}

16 year^{-1} and an average N output of 155 kg ha^{-1} year^{-1}. The low intensity systems had a

17 greater proportion of their N outputs as crop offtake (average 59%) compared with

18 leaching (31%) and volatilization (3%) (volatilization could amount to 10% where

19 manure was not incorporated quickly). The high intensity animal systems had a

20 greater proportion of their N output as leaching (41%) compared with crop offtake

21 (31%). Predictably, outputs as animal products and volatilization were greater in the

22 high intensity systems than in the low intensity systems. It appears, therefore that, in

23 these organic systems, efforts to increase animal production resulted in quantitatively

24 and proportionately more N being wasted through leaching and volatilization. This

25 might be expected because the process of converting atmospheric N to animal

          8

1 products via numerous cycles of forage plant growth, grazing and excretion is

2 inefficient. However, this is difficult to demonstrate conclusively with these farm

3 studies because the high intensity systems were also generally on soil types more at

4 risk of leaching.

5

6 In absolute terms, the largest source of error within the N budgets was from

7 estimates of biological fixation. The range of biological fixation was reviewed by

8 Watson *et al.* (2002); they concluded that a 1 to 2 year old white clover ley could fix

9 50% more or less N than that assumed in Table 3. This variability is so large that it

10 highlights the need to develop more precise methods of quantifying the effects of

11 legume species, soil pH, soil available N etc. on N fixation. Estimates of the amount

12 of N added in manures are often a large source of error in N budgets, but this was

13 minimised in this study through measurement. NITCAT was developed to estimate

14 leaching under conventionally managed systems, but was able to accommodate

15 organic systems because it had been based on data from experiments without

16 inorganic N fertilizer and measured values of soil organic matter were used for

17 estimating rates of mineralization. Nitrous oxide losses from the soil were not

18 estimated for these N budgets because they have been shown to be negligible in

19 grassland when applications of inorganic fertilizer were less than 100 kg N ha^{-1}

20 (Scholefield *et al.* 1991) and to only amount to losses of between 1 and 3 kg N ha^{-1}

21 year^{-1} in conventionally managed arable systems (Webb *et al.* 2000). Volatilization

22 losses of N from cut and mulched grass clover ley were found to be only 0.2 kg ha^{-1}

23 year^{-1} by Schmidt *et al*. (1999) and were therefore assumed to be negligible in these

24 budgets.

25

9

1   This study has shown that N budgets should be calculated using crop N contents

2   of produce from organic farms rather than conventional farms, e.g. the average N

3   content of conventionally produced wheat, barley, oats and potatoes (Alderman &

4   Cottrill, 1995) was about 20% greater than in organic crop produce (data from this

5   study and W. Cormack *pers. comm.*).

6

7   *Phosphorus*

8   The P budgets on 6 of the farms showed a positive budget (6 to 34 kg P ha^{-1} year^{-1})

9   while 3 had negative budgets (-1 to –8 kg P ha^{-1} year^{-1}). Other farm scale budgets

10   have measured a similar range of P budgets, -1 to 23 kg ha^{-1} year^{-1}, (Hermansten &

11   Kristensen 1998; Cuttle & Bowling 1999). Because P flows in rotational systems are

12   quantitatively much smaller than those of N (average outputs of 14 kg P ha^{-1} year^{-1} in

13   this study), the small deficits reported here, if widely applicable, may have a

14   significant impact on the sustainability of such organic systems even in the medium

15   term. However, in most cases the use of supplementary P fertilizer in the form of

16   rock phosphate (on 5 farms), corrected any potential P deficit. The large P surplus (34

17   kg P ha^{-1} year^{-1}) on Farm 1 would be removed if the supplementary P fertilizer (33 kg

18   P ha^{-1} year^{-1}) currently used was withdrawn. On Farms 4 and 7 the use of

19   supplementary feed for the non-ruminant livestock contributed to the P surpluses of

20   26 and 7 kg ha^{-1} year^{-1} respectively. This has been inferred from the manure returns

21   because imported feed was not accounted for directly in these P budgets. Whether or

22   not release of P from soil reserves is sufficient to match any net export of P within a

23   rotation depends upon soil type and past P manuring before conversion to organic

24   husbandry. The available P content in the upper 5cm of a sandy soil in the

25   Netherlands under a silaged grass/clover ley fell by 25% over 5 years, even when

10

1   manure was applied (Younie & Baars 1997). However on a non-sandy soil, an annual

2   P deficit of 2 to 4 kg P ha^{-1} caused no decline in the content of extractable P over 10

3   years (Kaffka & Koepf, 1989).

4

5   *Potassium*

6   None of the rotations received any supplementary K fertilizer, though the inputs of

7   rock phosphate contained small amounts of K (Table 4). The K budgets on 3 of the

8   farms showed a positive budget of 9 to 28 kg K ha^{-1} year^{-1}, one was perfectly

9   balanced (Farm 7) and on 5 farms there was a negative K budget of -21 to –52 kg ha^{-1}

10   year^{-1}. On Farms 1, 3 and 4 there were substantial inputs of manure to the fields being

11   studied and this returned more K than was removed. This occurred because the

12   livestock on these farms were fed with imported concentrates. On the other livestock

13   farms, inputs of K via manure were not sufficient to balance the removal in silage and

14   other crops, except Farm 7. Potassium leaching from the manure heaps was not

15   estimated for farms 1, 2, 3, 7 and 9 because either standard values for composted

16   manures were used or measurements of the manure were made several months before

17   the manure was applied to the land. Leaching from manure heaps may represent a

18   significant loss of K from the system. Godden & Penninckx (1997) reported values

19   from a number of studies showing losses during composting from 18 to 67% of the

20   original K content. On the two farms without stock there were large negative K

21   budgets of up to –52 kg ha^{-1} year^{-1}. Other studies have shown that livestock only farm

22   budgets are often positive for K (e.g. Cuttle & Bowling 1999), with mixed farms more

23   likely to have negative budgets (Nolte & Werner 1994). Askegaard and Eriksen

24   (2002) showed that the K budget of a mixed system changed from negative to positive

25   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.

REFERENCES

Alderman G & Cottrill BR 1995. Energy and Protein Requirements of Ruminants. An
   advisory manual prepared by AFRC Technical Committee on responses to
   nutrients pp 133-139.

Anon. 2000. Fertilizer Recommendations. (Seventh Edition). MAFF Reference Book
   209. HMSO, London.

Askegaard M & Eriksen J 2002. Exchangeable potassium in soil as indicator of
   potassium status in an organic crop rotation on loamy sand. Soil Use and
   Management 18, 84-90.

Bailey RJ & Spackman E 1996. A model for estimating soil moisture changes as an
   aid to irrigation scheduling, and crop water use studies: I Operational details and
   description. Soil Use and Management 12, 122-128.

Berry PM Sylvester-Bradley R Philipps L Hatch DJ Cuttle S & Raynes F & Gosling
   2002. Is the productivity of organic farms restricted by the supply of available
   nitrogen? Soil Use and Management 18, 248-255.

1   Chambers BJ Lord EI Nicholson FA & Smith KA 1999. Predicting nitrogen

2   availability and losses following land application of manures to arable land:

3   MANNER. Soil Use and Management 15, 137-143.

4   Cuttle S & Bowling PJ 1999. Nutrient budgets and soil fertility. In: Organic Milk

5   Production: Post-conversion Phase. Part 1. Report to MAFF for project No.

6   OF0113.

7   Fagerberg B Salomon E Jonsson S 1996. Comparisons between conventional and

8   ecological farming systems at Öjebyn. Swedish Journal of Agricultural Research

9   26, 169-180.

10 Fortune S Conway J S Philipps L Robinson J S Stockdale E A & Watson C 2000. N,

11   P and K for some UK organic farming systems – implications for sustainability. In:

12   Soil Organic Matter and Sustainability. CABI Wallingford, pp286-293.

13 Godden B & Pennickx M 1997. Management of farmyard manure composting is

14   important to maintain sustainability in organic farming. In: Resource Use in

15   Organic Farming. Proceedings of the 3rd ENOF workshop, eds J Isart & JJ

16   Llerena. Ancona pp 225-232.

17 Goulding KWT & Loveland PJ 1987. The classification and mapping of potassium

18   reserves in soils of England and Wales. Journal of Soil Science 37, 555-565.

19 Goulding KWT 1990. Nitrogen deposition from the atmosphere. Soil Use and

20   Management 6, 61-63.

21 Goulding KWT Bailey NJ & Bradbury P 1998a. A modelling study of nitrogen

22   deposited to arable land from the atmosphere and its contribution to nitrate

23   leaching. Soil Use and Management 14, 70-77.

Goulding KWT Bailey NJ Bradbury P Hargreaves P Howe M Murphy DV Poulton PR & Willison TW 1998b. Nitrogen deposition and its contribution to nitrogen cycling and associated soil processes. New Phytologist 139, 49-58.

Goulding KWT Stockdale EA Fortune S Watson CA 2000. Nutrient cycling on organic farms. Journal of the Royal Agricultural Society 161, 65-75.

Hermansen JE & Kristensen T 1998. Research and evaluation of mixed farming systems for ecological animal production in Denmark. In: Mixed Farming Systems in Europe, eds H Van Keulen EA Lantinga & HH Van Laar. Dronten, The Netherlands pp 97-101.

Jarvis SC 1993. Nitrogen cycling and losses from dairy farms. Soil Use and Management 9, 99-105.

Kaffka S & Koepf HH 1989. A case study in the nutrient regime in sustainable farming. Biological Agriculture and Horticulture 6, 89-106.

Kopke U 1987. Sybiotische Stickstoff-Fixierung and Vorfuchtirkung von Ackerbohnen (Vicia faba L.). Habilitation Thesis University of Gottingen.

Kristensen ES Hogh-Jensen H & Kristensen IS 1995. Estimation of biological N_2 fixation in a clover grass system by the ^{15}N dilution method and total N difference method. Biological Agriculture and Horticulture 11, 203-219.

Lord EI 1992. Modelling of nitrate leaching. Aspects of Applied Biology 30, 19-28.

National Expert Group on Transboundary Air Pollution (NEGTAP) 2001. Transboundary Air Pollution. Acidification, Eutrophication and Ground level Ozone in the UK. 1st Report. March 2001.

Nguyen ML Haynes RJ Goh KM 1995. Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. Agriculture, Ecosystems and Environment 52, 149-162.

16

1 Nolte C & Werner W 1994. Investigations on the nutrient cycle and its components of

2   a biodynamically-managed farm. Biological Agriculture and Horticulture 10, 235-

3   254.

4 Schmidt H Philipps L Welsh JP & Fragstein P von 1999. Legume breaks in stockless

5   organic farming rotations: Nitrogen accumulation and influence on the following

6   crops. Biological Agriculture and Horticulture 17, 159-170.

7 Scoones I & Toulmin C 1998. Soil nutrient balances: what use for policy? Agriculture

8   Ecosystems and Environment 71, 255-267.

9 Shepherd MA Bhogal A Lennarttson M Rayns F Jackson L Philipps L & Pain B 1999.

10   The environmental impact of manure use in organic farming. Report to MAFF for

11   Project No. OF0161.

12 Smith KA Charles DR & Moorhouse D 2000. Nitrogen excretion by farm livestock

13   with respect to land spreading requirements and controlling nitrogen losses to

14   ground and surface waters. Part 2: Pigs and poultry. Bioresource Technology 71,

15   183-194.

16 Sommer SG & Hutchings NJ 1997. Components of ammonia volatilization from

17   cattle and sheep production. In: Gaseous nitrogen emissions from grasslands, eds

18   SC Jarvis & BF Pain, CAB International Wallingford UK pp 79-94.

19 Stockdale EA Lampkin NH Hovi M Keatinge R Lennartson EKM Macdonald DW

20   Padel S Tattershall FH Wolfe MS & Watson CA 2001. Agronomic and

21   environmental implications of organic farming systems. Advances in Agronomy

22   70, 261-327.

23 Watson CA Bengtsson H Ebbesvik M Løes A-K Myrbeck A Salomon E Schroder J &

24   Stockdale EA 2002. A review of farm-scale nutrient budgets for organic farms in

25   temperate regions. Soil Use and Management 18 Supplement, 264-273.

1 Webb J Harrison R & Ellis S 2000. Nitrogen fluxes in three arable soils in the UK.

2   European Journal of Agronomy 13, 207-233.

3 Wood M 1996. Nitrogen fixation: How much and at what cost? In: Legumes in

4   sustainable farming systems, ed D Younie Occasional symposium of the British

5   Grassland Society No. 30 Proceedings of the Joint Conference of the British

6   Grassland Society and the Sustainable Farming Systems Initiative, SAC

7   Craibstone Aberdeen pp 26-35.

8 Whitehead DC 1995. Grassland Nitrogen. CAB International Wallingford UK.

9 Younie D & Baars T 1997. Resource use in organic grassland. The central bank and

10   art gallery of organic farming. In: Resource Use in Organic Farming. Proceedings

11   of the 3rd ENOF workshop, eds J Isart & JJ Llerena, Ancona pp 43-60.

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1 Table 1   Basic farm information and the crop sequence in the target rotation at each
2   farm.
3

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

4
5 Soil types: ca – calcareous; C – clay; L – loam; S – sand; Z – silt.
6
7 Crops: Beet – fodder beet; Ley – white clover / ryegrass ley; Pigs – pigs on stubble; RC – Red clover;
8   SB – spring beans; SBa – spring barley; SC – spring cereal; SO – spring oats;
9   SW – spring wheat; WB – winter beans; WC – winter cereal; WO – winter Oats;
10   WW – winter wheat; WT – winter triticale.
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1   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	✓

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3   ✓   Exact information obtained
4   *   Estimates made from observation or other information
5   N/A   Not applicable
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20   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

1 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
2 the quantification of inputs and outputs are described in the text.
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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**

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

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                    ┌───────────────┐
                    │   LIVESTOCK   │
                    └───────────────┘
                         │      ↑
                     Manure   Animal off take
                         │      during grazing
          Seed           ↓      │
              ↘     ┌──────────────────────┐
          N fixation │                      │
              ↘      │                      │        Crop offtake
                     │        FIELD         │ ──────→
          Aerial     │                      │
          deposition │                      │
              ↗      └──────────────────────┘
          Fertilizing    │            │
          material       ↓            ↓
                      Leaching    Volatilization
```

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