Available online at www.sciencedirect.com
ScienceDirect
Agriculture, Ecosystems and Environment 119 (2007) 160–170
Agriculture Ecosystems & Environment
www.elsevier.com/locate/agee

Barn balance calculations of Ca, Cu, K, Mg, Mn, N, P, S and Zn in a conventional and organic dairy farm in Sweden

Gunnela M. Gustafson [a,*], Eva Salomon [b], Simon Jonsson [c]

[a] *Centre for Sustainable Agriculture, P.O. Box 7047, Swedish University of Agricultural Sciences, SE-75007 Uppsala, Sweden*
[b] *Swedish Institute of Agricultural and Environmental Engineering, Box 7033, SE-75007 Uppsala, Sweden*
[c] *Swedish University of Agricultural Sciences, SE-94331 Öjebyn, Sweden*

Received 23 January 2006; received in revised form 27 June 2006; accepted 5 July 2006
Available online 7 September 2006

Abstract

Calculations of flows and balances of plant nutrients in agricultural production systems provide some basic information for the assessment of their long-term sustainability. The objectives of this study were to assess the possible impacts of variations in element concentrations between years and of undefined sinks and sources of elements on the accuracy of balance calculations. A 3-year study was conducted on Ca, Cu, K, Mg, Mn, N, P, S, and Zn fluxes in the barns (subsystem) of a Swedish farm with separate conventional and organic milk production. Our main focus in this subproject was on barn balance calculations, the barn housing only cows. Barn balance for an element was defined as amount of that element in [feeds, heifers, bedding, water] − [milk, manure, urine, calves, culled cows]. The focus was on: (1) variations in element concentrations in the main flow carriers [feeds, milk, manure, urine]; (2) information about element dynamics and flows of dairy farming systems obtained from internal flows of elements in the barn balance compared with that obtained from the flows associated with milk production in a farm gate balance; (3) differences in element flows and concentrations between the organic and conventional farming systems on this farm.

Our conclusions were: (1) the sampling methods used had low coefficients of variation and thus pooled samples can reduce the costs of element analyses. However, urine must be thoroughly mixed if less water-soluble elements are to be monitored. Magnesium differed significantly in concentrations between years in all feedstuffs; (2) year-to-year fluctuations in harvest can influence a calculation negatively if calculations are based on annual harvest and not on feed supplied. The barn balance calculation showed a source of Cu, Mn and Zn that would not have been obvious in a farm gate balance. The element content of manure and urine calculated as [inputs – milk] would have underestimated the amount of Cu, Mn and Zn in manure and overestimated the amount of K and N. The Cu analysis showed an example of conflicting goals between short-term welfare of the cows and long-term soil fertility. EU legislation regarding land for spreading of manure is not a guarantee against soil contamination by heavy metals; (3) the differences between the organic and conventional system related more to differences in forage: concentrate and home-grown: purchased ratios, which were typical for the average Swedish farm of each type, and less to differences in element concentrations of the feed ingredients.

Keywords: Concentrations; Feeds; Manure; Milk; Plant nutrient flows; Sinks; Soil accumulation; Sources; Urine

1. Introduction

Calculations of flows and balances of nutrients in an agricultural production system provide some basic information for the assessment of its long-term sustainability. For this reason, studies on nutrient balances at farm level (farm gate balances) have become a useful tool during the past 10 years, as problems with surpluses of nutrients in industrialised agriculture have become relevant for the health of the biosphere. Nitrogen (N) and phosphorus (P) are by far the most studied elements, probably because of the obvious environmental problems they create (e.g. Gibon et al., 1999; Smaling et al., 1999). However, the threat of heavy metal

* Corresponding author. Tel.: +46 18 67 16 52; fax: +46 18 67 35 71.
E-mail address: Gunnela.Gustafson@huv.slu.se (G.M. Gustafson).

0167-8809/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2006.07.003

contamination for human and ecosystem health is also in focus. Since 1990, the International Conference on Biogeochemistry of Trace Elements has convened regularly to deal with this issue (ICOBTE, 2006). Andersson (1992) and Poulsen (1998) expressed concerns about excess inputs of heavy metals such as Cu and Zn to soils. They considered animal feed to be an important source of soil contamination through manure.

When the outputs of a particular element from a farm equal the farm inputs, this is considered to be a sustainable situation for the environment concerning that specific element (Oenema et al., 2003). Those authors suggest that farm gate element budgets are more integrative than soil surface or soil system element balances because they can be calculated with greater accuracy, but subsystem budgets can be a good complement. In a farm gate balance, the internal element circulation is hidden, which can be a restraint on the possibilities of making adequate proposals for improvements of the total farm nutrient budget. When advancing into internal flows for field and barn balances, the difficulties in obtaining precise information increase due to the complexity of the farming system and the difficulty in correlating flows of inputs to outputs. Öborn et al. (2003) present a thorough overview of benefits, limitations and uncertainties of different types of element balances. The spatial and temporal distribution of element flows relate to the conditions for production and the aims of the farmer (Bacon et al., 1990). Lanyon and Beegle (1989) and Pitt (1995) used a hierarchical classification of farm units for assessing element flows and the influence of changed management strategies on element flows at farm level and between farm compartments such as field, barn and manure. Pitt (1995) concluded that a substantial improvement for the farm could only be achieved by simultaneous improvements in several internal processes. We elaborated on this idea in a 3-year research project at the Swedish University of Agricultural Sciences (SLU) (Öborn et al., 2005). The focus was on the flows and stores of several macro and trace elements at farm level (Öborn et al., 2005), barn level (Gustafson et al., 2003) and field level (Bengtsson et al., 2003; Bengtsson, 2005) in time spans ranging from the annual cropping season to 3 years. The project formed part of a longer study at the Öjebyn Research Farm, SLU. For 12 years, the farm had been partitioned into two farming systems for milk production—one organic and one conventional according to Swedish standards (Jonsson, 2004).

Gustafson et al. (2003) present results from a 1-year study of K, P and Zn fluxes connected to the milk production subsystems of the Öjebyn farm. The present paper deals with a 3-year study of Ca, Cu, K, Mg, Mn, N, P, S, and Zn fluxes in the same subsystems, focusing on three questions: (1) What is the variation in element concentrations of the main flow carriers (feeds, milk, manure, urine)? (2) What information about the element dynamics and flows of dairy farming systems is obtained from internal flows of elements in the milk production subsystem compared with that obtained from the flows associated with milk production in a farm gate balance, and could hidden sinks and sources be detected? (3) Are there differences in element flows and concentrations between the organic and conventional farming systems at this farm?

2. Materials and methods

2.1. Definitions of terms used

Barn balance for an element is the amount of that element in: [feeds, heifers, bedding, water] − [milk, manure, urine, calves, culled cows]. Manure and urine were included in the barn balance until the day of spreading on the fields. *Reduced farm balance* for an element is the amount of that element in: [purchased feeds, heifers, water] − [milk, culled cows]. The terms *import* and *export* relate to materials that are purchased in or sold from the farm, whereas *input* and *output* relate to the barn balance. *Internal flows* never leave the farm and go with silage, barley produced on-farm, straw, manure and urine. *External flows* pass the farm gate in either direction and consist of purchased barley, concentrates, molassed beet pulp, wood shavings, water, milk, calves, heifers and culled cows. *Silage* is ensiled grass and clover. *Concentrates* are usually mixtures of protein-rich feeds such as rapeseed meal and soya-bean meal. At our farm, mineral supplements and salt were also included with the concentrates. *Feed fed* is what is recorded in the barn as fed according to the nutrient requirements of the cows. *Feeding balance* for an element is the amount in feeds fed − calculated requirements for the milk produced.

2.2. The research farm

The research farm at Öjebyn is situated on the coastal plain of northern Sweden (65°N 21°E) and has been in operation since 1946. The mean annual temperature at the site is +2.1 °C and the average precipitation is 500 mm (Hårsmar, 1991). Three soil types were identified by Bengtsson (2005), namely Eutric Regisols, Thionic Gleysols and Dystric Cambisols (FAO, 1998). The growing season is from mid-May to mid-September. The area is suitable for production of forage, barley, potatoes and vegetables.

In 1989, the farm was divided into a conventional and an organic dairy farming system with 40–50 cows in each system. The conventional system has 47 ha of arable land, of which 7 ha is permanent pasture. The organic system has 58 ha of arable land, of which 10 ha is permanent pasture. All soil types found on the farm occur in both systems. The crop rotation in both systems includes 1 year of 80% peas and 20% oats with undersown ley, 3 years of clover/grass ley, 1 year each of barley and potatoes. Each system has a separate cowshed for tethered cows. All cows are kept on pasture 6–10 h day^{-1} between June and August. The bull calves are raised at another farm from the age of 1 week, the