SCOPING EXERCISE AND LITTERATURE SEARCH ON THE RELEVANCE AND PRACTICALITY OF USING ORGANIC FARMING PRACTICES AS AN ALTERNATIVE LAND MANAGEMENT PRACTICE ON AGRICULTURAL LANDS TO GUIDE FUTURE WORK ON ACHIEVABLE PERFORMANCE STANDARDS (APSs)

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1 INTRODUCTION

At the end of 2007, 32.2 millions hectares of land, representing about 0.73% of the agricultural land of the surveyed countries, were managed according to organic standards around the world (IFOAM, 2009). The global market for organic products then reached a value of over 46 billion US Dollars, with the vast majority of produce being consumed in North America and Europe (IFOAM, 2009).

Although many cultures traditionally practiced a form of agriculture that can be considered organic with regards to actual standards, the organic movement, as it is known today, began with the 20th century as a reaction toward new technologies and new farming practices that led to the Green Revolution. The widespread use of gasoline-powered tractors, of synthetic fertilizers, of hybrid seeds issued from development in plant breading, of chemical pesticides following World War II, of large scale irrigation, and, more recently, of Genetically Modified Organisms (GMOs), all contributed to transform traditional farming practices in order to feed an ever increasing population. To optimise the use of machinery, cropland expanded and crops became more specialized in order to use machinery more efficiently. Traditional seedlings were replaced by more productive hybrid varieties, and ancient practices to maintain soil health were replaced by massive use of artificial fertilizers. As a consequence, total field yield increased, but crops became more vulnerable to pest and disease. Pesticides and genetic engineering became the solution to maintain high productivity. As population became more and more concern with the environmental impact of such practices, organic farming associations and institutions formed all around the world, and along came the certification process.

The International Federation of Organic Agriculture Movement (IFOAM) was founded in France, in 1972. Today the IFOAM unites 750 member organizations in 108 countries, and produces standards which have provided a model for numerous major laws and voluntary standards (IFOAM, 2009).

The increasing demand for organic products recently led to the development of legislation and standards by governments. Canada's Organic Products Regulations (OPR) will be effective on June 30, 2009. The question has been raised on the relevance and practicability of using organic farming practices as an alternative land management practice on agricultural land to guide future work on achievable performance standards (APSs). In other words, how can organic farming affect water quality, and how that effect could be taken into account by the hydrological modelling framework developed by Rousseau *et al*. (2008) and used for APS determination.

This report is organized in eight chapters. Chapter 7 provides an answer to the aforemetioned question. A first look at data requirements to introduce organic farming practices as an alternative land management scenario within a hydrological modelling framework is introduced in Chapter 4, followed by a brief synthesis of the environmental impact associated with organic farming in Chapter 5. Chapter 6 presents a literature review to provide an overlook of at what has been done so far to model the impact of organic farming practices on surface water quality. But first, Chapter 2 introduces a brief historical review of the organic farming paradigm along with basic definitions and standards of organic farming from USA, Europe, Japan and Canada. This is followed by an overview of the major crops grown in Canada within an organic farming system (Chapter 3).

2 HISTORICAL REVIEW, DEFINITION, AND STANDARDS OF ORGANIC FARMING

2.1 HISTORICAL REVIEW

Sir Albert Howard (1873-1947) is considered by many to be the founder of the organic agriculture movement (Heckman, 2006). After a career spent in India in several agricultural research centres, he published books where he exposed his concept of soil fertility centered on building soil humus with an emphasis on a "living bridge" between soil life, such as mycorrhizae and bacteria, and how this chain of life from the soil supported the health of crops, livestock and mankind (Howard, 1972 *in* Heckman, 2006). Rudolf Steiner (1861-1929), an Austrian thinker, founded in 1924 biodynamic agriculture, a branch of organic farming. A central aspect of biodynamics is that the farm as a whole is seen as an organism, and therefore should be a closed, self-nourishing system. Disease of organisms is not to be tackled in isolation but is a symptom of problems in the whole organism. The term "organic farming" was first introduced in 1940 with the publication of *Look to the Land* by Lord Northbourne (1896-1982), from the conception of the farm as an organism. The book described a holistic, ecologically-balanced approach to farming.

The first, long-term scientific experiment to compare organic and non-organic farms was conducted in England from 1939 to 1969 by Lady Eve Balfour (1899-1990). Her observations were published in *The Living Soil and the Haughley Experiment* (1943, 1974). In 1946, she co-founded and became the first president of the Soil Association, an international organization claiming to promote sustainable agriculture (and the main organic farming association in the UK today).

In 1942, Jerome Irving Rodale (1898-1971) contributed to spread the organic movement ideas in America with the publication of the magazine *Organic Farming and Gardening* (later *Organic Gardening*).

Thirty years later, in 1972, the IFOAM was founded in France. First active there, along with the German-speaking countries and an early participation in Canada, IFOAM activities soon widened, by the 80s, to encompass the US, African agents of organic agriculture, and a relationship was established with the Food and Agriculture Organization of the United Nations (FAO). The organisation is now active in 108 countries (IFOAM, 2009).

Certification by private associations began during the 1970s, and governments started to write organic production guidelines during the 1980s. Legislation of standards began in the 1990s. In 2007, more than 60 countries had legal framework for organic production (IFOAM, 2009).

2.2 DEFINITION

IFOAM has defined the four basic principles of the Organic Movement from which organic agriculture grows and develops. These principles express the contribution that organic agriculture can make to the world and a vision to improve all agriculture in a global context. They guide IFOAM's development of positions, programs and standards.

1. **Principle of health**

Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.

2. **Principle of ecology**

Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.

3. **Principle of fairness**

Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities

4. **Principle of care**

Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

Using these principles, IFOAM proposed a short definition of organic agriculture:

"Organic agriculture is a food production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted

to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."

(IFOAM, 2009)

The above definition, presented in December 2007, was meant to be short, to cover full diversity of organic agriculture in the world, and to be formulated in a positive way. It can be further refined by listing some agricultural practices that distinguish organic farming from conventional farming, including (Forges, 2004):

- a prohibition on chemical fertilizers and pesticides, plant and animal growth regulators, hormones, antibiotics, preservatives, *etc*.;
- a prohibition on GMOs;
- a prohibition on soil-less culture (which does not preclude greenhouse growing);
- the requirement, in the case of animal production, to allow free-range practices, to use organically produced feed, to limit animal density in building, *etc*.; and
- the requirement to observe conversion periods in crop production before any produce can be marketed as "organic", *etc*.

In order to maintain soil productivity, and to control pest and disease without using chemicals, organic agriculture relies on crop rotation, green manure, compost, biological pest control and mechanical cultivation.

2.3 STANDARDS

To insure that a certain product is produced according to organic agriculture principles, it must be certified by a proper regulatory body. The certification is the guarantee that the product was obtained according to standards that insure the respect of the organic principles. However, the increasing number of certification bodies (395 organizations worldwide in 2007; IFOAM, 2009) and the proliferation of standards bring some confusion to consumers, and raise the issue of equivalences among the different certifications. In order to preserve the integrity of the "organic" label, and to facilitate organic product marketing between states, provinces, or countries, many governments (more than 60 countries in 2007; IFOAM, 2009) have adopted legislations that guarantee a "uniform minimum set of standards". Base on these legislations, governments can give accreditations to the certification bodies whose standards meet, or are more restrictive, than government's standards. A special seal, or logo, is used to insure that an organic product meets a government and/or certification body standards.

2.3.1 Organic Standards around the world

2.3.1.1 United States legislation

The Federal Organic Foods Production Act of 1990 establishes the national standards governing the marketing of organically produced products in the US. Initially, the proposed standards did not prohibit the use of sewage sludge, food irradiation and GMOs. That changed in October 2001 with the adoption of the National Organic Program (NOP) of the US Department of Agriculture (USDA). It is now under NOP that the USDA develops, implements, and administers national production, handling, and labelling standards for organic agricultural products. Also, NOP accredits the certifying agents (foreign and domestic) who inspect organic production and handling operations to ensure that they meet USDA standards (USDA, 2009).

2.3.1.2 European Union legislation

The European Council of Agricultural Ministers adopted Regulation No. 2092/91 on organic farming and the corresponding labelling of agricultural products and foods in 1991. The introduction of this Regulation was part of the reform of the EU Common Agricultural Policy and represented the conclusion of a process through which organic agriculture received the official recognition of the 15 states which were EU members at the time. That regulation created common minimum standards for the entire EU, letting the member states and private organisations to enact their own additional stricter standards. Since then, a new Council Regulation (No. 834/2007) was adopted in 2007, replacing No. 2092/91. Two new Commission Regulations were also adopted in 2008 regulating organic production, import and distribution of organic products as well as their labelling. These new regulations went into effect on January 1, 2009, for the production, control and labelling of organic products. However, some of the new provisions on labelling will only take effect on July 1, 2010 (European Commission, 2009).

2.3.1.3 Japanese legislation

The Japanese Agricultural Standard (JAS) for organic plants and organic processed foods of plant origin was established in 2000 and based on the Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods which were adopted by the Codex Alimentarius Commission. It was updated in November 2005 with the addition of standards for organic livestock products, organic processed foods of animal origin and organic feeds (Japan Ministry of Agriculture, Forestry and Fisheries, 2009).

2.3.2 Organic Standards in Canada

Prior to a Canadian legislation on organic agriculture, the provinces of Quebec and British Columbia had already established their own minimum provincial standards, as well as a procedure for accrediting organic farming certification bodies.

In Quebec, the *Conseil des Appellations Réservées et des Termes Valorisants* (CARTV; formerly the CAAQ), is the control authority appointed by the Quebec Ministry of Agriculture, Fisheries and Food to accredit bodies that comply with the applicable accreditation manual as certification bodies, to advise the Minister on the recognition of reserved designations, and to monitor the use of recognized reserved designations. The Quebec Organic Reference Standards define the standards of organic agriculture in Quebec (CARTV, 2009).

In British Columbia, the Organic Agricultural Products Certification Regulation under the *Food Choice and Disclosure Act* designated the Certified Organic Associations of British Columbia (COABC) as the administrator of the regulation to implement a government audited accreditation and standard setting program for organic certification. The standard for production and the system of farm inspection and certification spelled out in the British Columbia Certified Organic Program (BCCOP) were developed by COABC in collaboration with the British Columbia Ministry of Agriculture and Lands (formerly the British Columbia Ministry of Agriculture, Food and Fisheries). The *Food Choice and Disclosure Act* was replaced by the *Agri-Food Choice and Quality Act* in 2000, and allowed for the certification of non-food products and clarified some aspects of certification for handlers and retailers (British Columbia Ministry of Agriculture and Lands, 2007).

On June 1999, the Standard Council of Canada approved a national standard for organic farming, developed jointly by the Canadian General Standards Board (CGSB) and the Canadian Organic Advisory Board (COAB). The standard was voluntary based and did not constitute a minimum for organic production in Canada. It was in December 2006 that Canada's Organic Products Regulations (OPRs) was first published in the Canada Gazette. The new Canadian Organic Regime (COR) is the mandatory system to federally regulate the organic integrity of products in Canada. It is based on four main documents:

1. The OPRs – new regulations under the authority of the Canadian Agricultural Products Act;
2. The Organic Production Systems General Principles and Management Standards, CAN/CGSB-32.310 – developed by the organic industry and the Canadian General Standards Board;
3. The Organic Production Systems Permitted Substances List, CAN/CGSB-32.311 - developed by the organic industry and the Canadian General Standards Board;
4. The COR Quality Management System (QMS) Manual.

The OPRs were under the authority of the Canadian Agricultural Product Act, and are administered by the Canadian Food Inspection Agency (CFIA). The CFIA works via third-party "Accreditation Advisory Bodies" that accredit the "Certification Bodies" which are responsible for organic farm certification.

OPRs were meant to regulate all Canadian businesses engaged in international or interprovincial trade, and all businesses that import to Canada or buy Canadian organic products. The regulations make the Canadian organic standards and permitted substances list mandatory for *all* organic food and livestock feed products sold in Canada, regardless of organic status under other regulatory programs. These products will be able to opt in to displaying the "Biologique Canada Organic" seal. It was first stated that OPRs would be implemented on December 14, 2008. But on September 2008, an official amendment to the OPRs was published in the Canada Gazette, delaying implementation of the new regulations and standards until June 30, 2009.

The Organic Production Systems General Principles and Management Standards (CAN/CGSB-32.310) define the new Canadian standards for organic production. It sets general rules, as well as specific rules applying to crop production, livestock production, and specific production (apiculture, maple products, mushroom production, sprout production, greenhouse crops production, and wild crops).

The Organic Production Systems Permitted Substances List (CAN/CGSB-32.311) defines the substances allowed for organic production. Thus, any substance *not* on that list is prohibited by the OPRs.

3. MAJOR CROPS IN CANADA GROWN WITHIN AN ORGANIC FARMING SYSTEM

3.1 STATISTICS

Sustainability of agriculture, environmental concerns and food safety issues have all contributed to the growth of organic farming in Canada. The 2006 Census of Agriculture results show that 15 511 (6.8%) of all Canadian farms reported growing organic products for sale in 2006. Farms producing organic, but not certified commodities outnumber both certified organic farms and farms that are in transition to becoming certified (Table 1). These farms differ in the type of commodities produced. Farms that are reporting organic but not certified products are more likely to report animal production (Statistics Canada, 2009).

Table 3-1 Farms producing organic products, by certification status, Canada, 2006 (source: Statistics Canada, 2009 - Census of Agriculture 2006)

Certification Status	Number of farms reporting	Percentage of all farms in Canada
Organic but not certified	11 937	5.2%
Certified organic	3 555	1.5%
Transitional	640	0.3%

When only the organic certified farms are considered, hay or field crops is the dominant production (Figure 3.1). If the uncertified organic farms are considered, animals or animal products become the dominant production. Farms producing hay or field crops, certified or not, account for 38% of the total reported organic farms. The proportion for animals or animal products is 34%, and it is 18% for fruits, vegetables or greenhouse products. Maple products and other organic products both account for 5%. Saskatchewan is the province with the most certified farms, and Ontario is the province with the most organic farms, certified or not, followed by British Columbia, Alberta, Quebec and Saskatchewan (Figure 3.2).

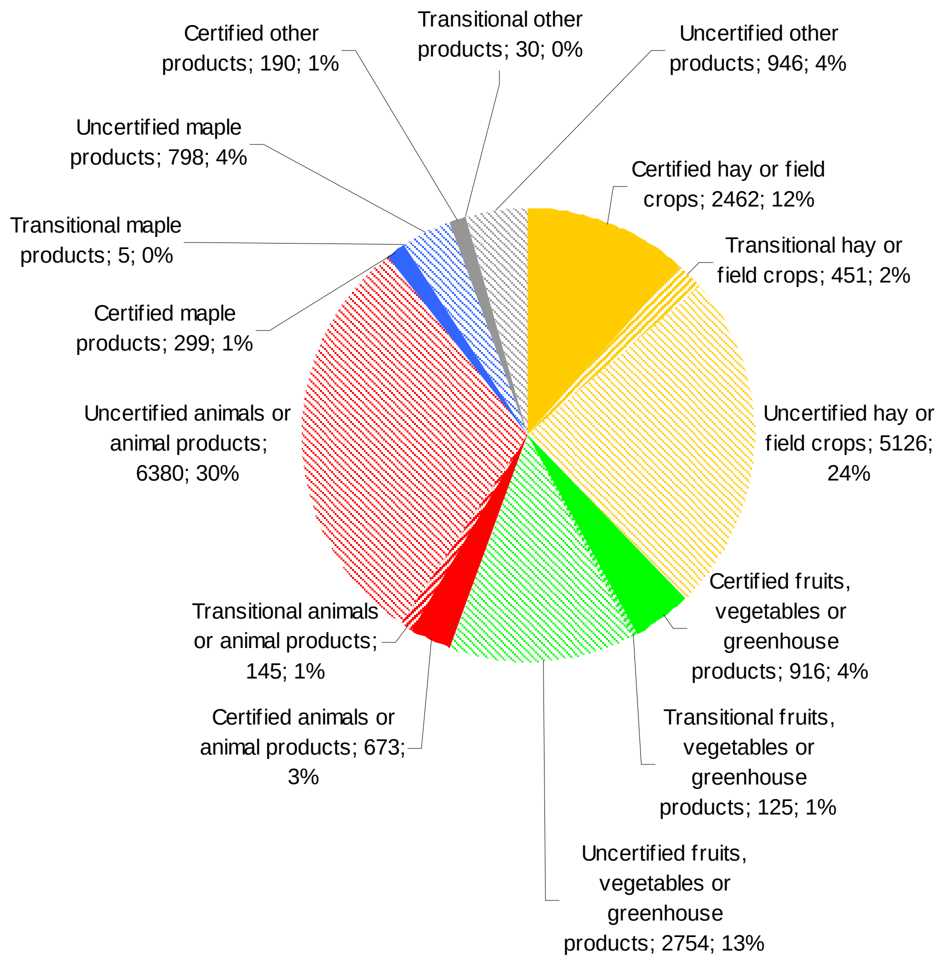

Figure 3-1 Certified, transitional, and uncertified organic farms in Canada, 2006 (Statistic Canada, 2009 - Census of Agriculture, 2006)

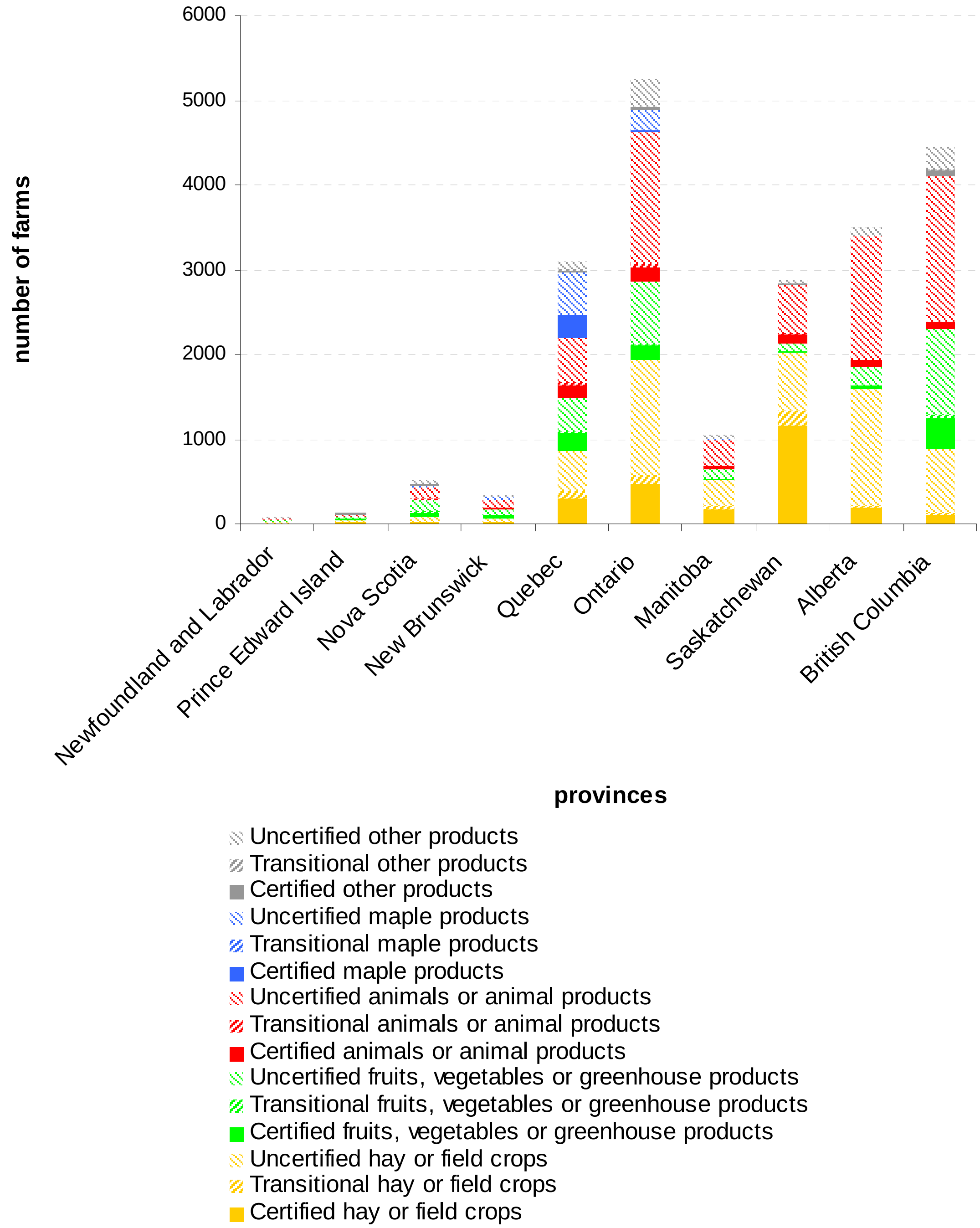

Figure 3-2 Certified, transitional, and uncertified organic farms by provinces in Canada, 2006 (Statistic Canada 2009 - Census of Agriculture, 2006)

3.2 DESCRIPTION OF THE MAJOR ORGANIC FARMING SYSTEMS (FIELD CROPS)

Organic farming systems are characterized by a prohibition to use pesticides and synthetic fertilizers. Weed, pest and disease control must be achieved through an integrated and preventive approach combined with the use of mechanical interventions. Nutrients are imported through organic manure application and the use of green manure. The use of catch crops and cover crops are also used to limit erosion and leaching of nutrients. Crop rotation is the core of organic agriculture since it allows to maintain a balanced ecosystem for weed, pest and disease control, and to maintain a sufficient nutrient pool in the soil. Many factors, such as value as cash crop or livestock feed, soil-building, nutrient conservation, weed and pest control, and demands on labour, equipment and knowledge must be considered when selecting crops in a crop rotation (Wallace, 2001). Canadian Organic Growers Inc. has produced an organic field crop handbook (Wallace, 2002) to help farmers in designing an organic crop rotation. Some tools, such as ROTOR (Bachinger and Zander, 2007) are also available to help farm managers to evaluate crop rotations that fit best according to the economical, physical, and environmental conditions. Since organic crop rotation is based on specific conditions that can differ from one region to another; and even from one farm to another, there is no "typical" organic crop rotation. Some examples of rotations used in Canada are given in the organic field crop handbook (Wallace, 2001) and in a transition kit toward organic agriculture (Fédération d'Agriculture Biologique du Québec, 2006) (see Appendix A).

When modelling organic crop rotations at a regional or national level, different approaches can be used according to study objectives. Pelletier *et al*. (2008), simply added a single sweet clover intercrop or cover crop to the conventional corn-soy and canola-wheat rotations when evaluating potential eco-efficiency of transition to organic agriculture in Canada. Another approach was used by Knudsen *et al*. (2006), who made a 10-year "regional" rotation by using field crop area statistics of a single year (appendix F, table 2).

4 APS MODEL REQUIREMENTS

Achievable Performance Standard or APS refers to a maximum concentration of a water contaminant (pesticide, nutrients, microbiological contaminants), allowed in surface waters at a given location on a river. For example, Rousseau *et al*. (2008, 2007a,b; 2006) used GIBSI (Rousseau *et al*., 2000, 2005; Quilbé and Rousseau, 2007) to develop a hydrological modelling framework for defining watershed-scale achievable performance standards of pesticides beneficial management practices. Within this modelling framework the fate of pesticides and nutrients and their concentration in surface waters of a river network is calculated by a series of models that are runned in a sequence. This chapter provides an overview of the data requirements to introduce organic farming practices as an alternative land management scenario within a hydrological modelling framework such as that provided by GIBSI.

GIBSI is a software integrating hydrological, erosion, pesticides and pollutant transport, and water quality models, along with a GIS and a relational data base management system (Rousseau *et al*., 2000, 2005; Quilbé and Rousseau, 2007). It was developed as a management tool to assess, *a priori*, the impact of different water and land management scenarios on water quality at the watershed scale. Input data necessary to run the different models include raster maps of elevation, soil, and land cover of the watershed, meteorological data (daily precipitations, minimum and maximum temperatures), a description of farming practices for the different crops on the watershed (crop rotations, agricultural practices, pesticides used, fertilization scenario, rate and time frame of pesticide and fertilizer applications). The output of each model is simulated on a daily time step. Computation for all models is made on sub-watersheds, called Spatial

Simulation Units, or SSUs, and on the river segment draining each SSU. The size of the SSUs can vary according to the modelling objectives. Calibration of the hydrological model and water quality model with observed stream flows, pesticide and nutrient concentrations is necessary for each watershed. Figure 4.1 illustrates in a simplified way the information required by each model in GIBSI adapted for APS determination, and the level at which the simulated organic agriculture can affect the chain of models. The models are briefly described thereafter.

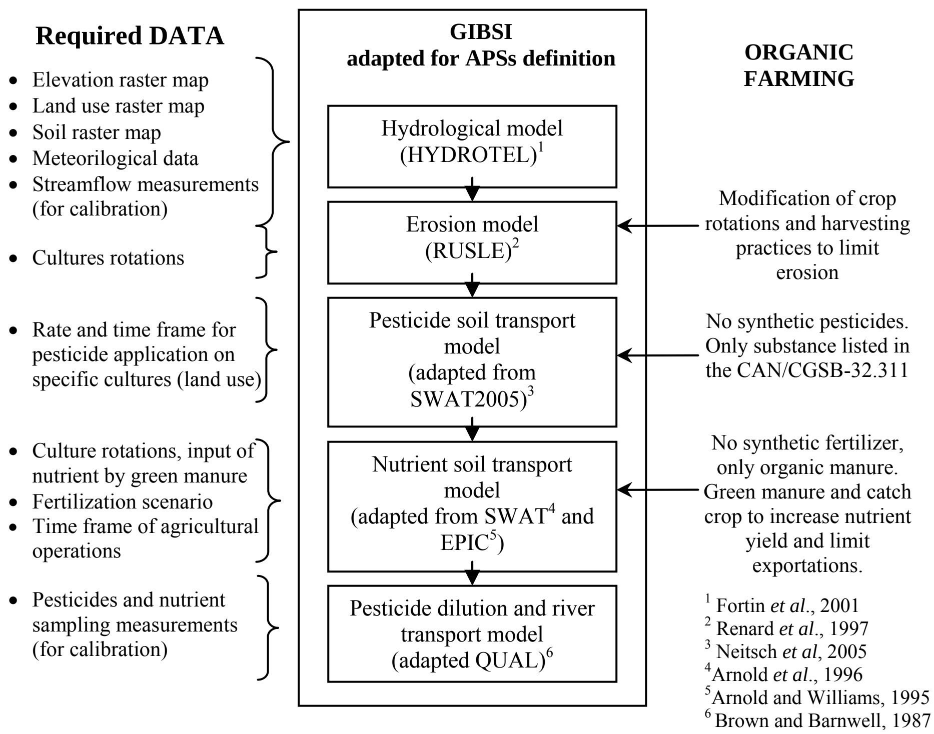

Figure 4-1 Illustration of data needed by the models in GIBSI, and the level at which those are influenced by organic farming practices for APS determination

4.1 Hydrological model

The core of GIBSI is the hydrological model HYDROTEL (Fortin *et al*., 2001). The model computes six hydrological processes: meteorological data interpolation on each

SSU (using either the Thiessen approach or an inverse distance approach based on the three closest stations), snow accumulation and melt (using a mixed degree-day and energy balance method), potential evapotranspiration (using a choice of algorithms depending on available meteorological data), soil vertical water balance (using a three-layer conceptual soil model), overland flow on each SSU (using reference geomorphologic hydrographs computed using the kinematic wave equation), and water routing in the river network (using the kinematic wave equation). Organic farming practices do not influence this model.

4.2 Erosion model

The erosion model is an adaptation of the Revised Universal Soil Loss Equation (RUSLE; Renard *et al*., 1997), and computes, using outputs from the hydrological model, edge-of-the-field daily sediment loads to the river system according to the different agricultural land covers in a given SSU. The equation is based on an erosivity factor (*R* factor, related to precipitation and surface runoff), an erodability factor (*K* factor related to soil texture, structure, and permeability), length and slope characteristics (*LS* factor) a vegetation factor (*C* factor, related to land cover, growth period, and crop rotations), and an erosion control factor (*P* factor, related to soil conservation practices). Organic farming practices will influence that model by modifying the *C* factor, related to vegetation cover and crop rotation, in RUSLE. A proper *C* value must be determined for each crop rotation of the organic farming scenarios.

4.3 Land pesticide transport model

The land pesticide transport model is an adapted version of SWAT (Arnold and Fohrer, 2005) and computes the total load of pesticide exported from agricultural fields to the river segment of each SSU. It uses outputs from the hydrological and erosion models as inputs, as well as pesticide application rates for a time frame for each crop type according to the land cover map. The model accounts for: (i) volatilisation during application, (ii) interception by crop foliage, and (iii) the remaining fraction reaching the ground surface. That last fraction is further divided into two parts: a dissolved part in the soil solution, and an adsorbed part to soil particles. The partitioning depends on the distribution coefficient (K_{oc}) particular to the sorption of each pesticide to the soil organic matter (*OC*). The pesticides intercepted by the foliage will degrade and dissipate by different processes: photolysis, oxidation, hydrolysis, volatilisation, and biodegradation. All those dissipation and degradation processes are simulated by a first-order decay equation using a half-life value, also specific to a given pesticide. Pesticides dissolved in the soil solution can reach the river through surface runoff or infiltration, while pesticides attached to soil particles are transported *via* erosion. Both hydrological and erosion models outputs are used as inputs to simulate transport of pesticides from cropland. Note that the model neither simulates the fate of pesticides lost to the atmosphere or absorbed by plants and the complex evolution of metabolites. The adsorption, soil half-life time, and solubility values used for the modeled pesticides were taken, in previous studies, from the database provided by Hornsby *et al*. (1996). Since all pesticides, except pyrethrum for mushroom production and some domestic formulations of rotenone, are prohibited by Canadian organic agriculture standards, no pesticide inputs should be modelled on organic farms for APS determination.

4.4 Land nutrient transport model

The land nutrient transport model is adapted from both SWAT (Arnold *et al*., 1996) and EPIC (Arnold and Williams, 1995). It simulates the nitrogen and phosphorus cycles, from their inputs as crop residues, fertilizer, nitrogen fixation, or precipitation to their washing by surface runoff and underflow, by taking into account the main chemical transformations and transfer that occur in the soil; and the uptake by growing crops. Figures 4.2 and 4.3 show the modelled phosphorus and nitrogen cycles in GIBSI. The use of crop rotations and green manure in organic farming influence the nutrient cycles in the soil, and their vulnerability to leaching. The equations used to model the different nutrient cycles processes are described in Lasbleis *et al*. (2008). A close examination of how the simulated processes are affected by the organic farming practices, namely here the use of green manure and catch crop, is required in order to assess how organic farming can be taken into account by GIBSI.

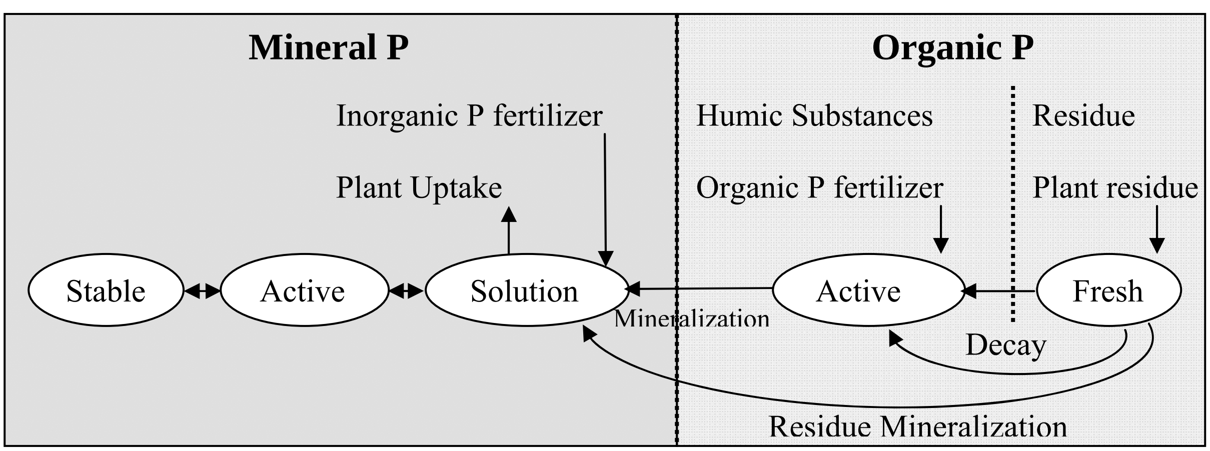

Figure 4-2 GIBSI soil phosphorus pools and processes that move P in and out of pools

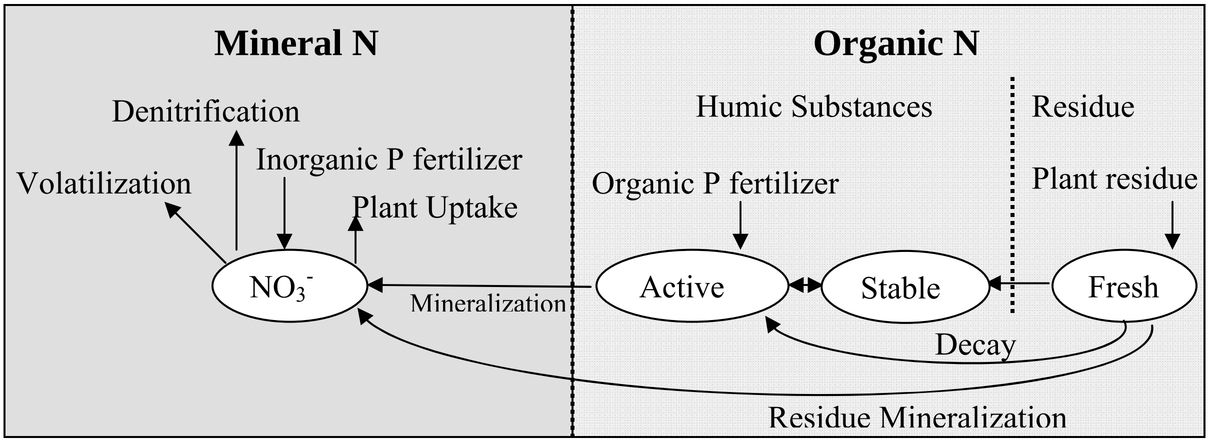

Figure 4-3 GIBSI soil nitrogen pools and processes that move N in and out of pools

4.5 Water quality model

The basic equation solved by the adapted QUAL2E model (Brown and Barnwell, 1987) in GIBSI is the one dimensional advection dispersion mass transport equation, which is numerically integrated over space and time for each water quality constituent (river segment). This equation includes the effects of advection, dispersion, dilution, constituent reactions and interactions, sources and sinks. For any constituent, *C*, this equation can be written as:

$$\frac{\partial C}{\partial t}=\frac{1}{A_x}\frac{\partial\left[A_x D_L \frac{\partial C}{\partial x}\right]}{\partial x}-\frac{1}{A_x}\frac{\partial\left[A_x u C\right]}{\partial x}-\frac{C}{A_x}\frac{\partial A_x}{\partial t}+\frac{dC}{dt}+S$$

Where :

C: Concentration of the constituent C (M L^{-3})

x: Position (L)

t: Time (T)

A_x: Cross-section area of the channel (T^2)

D_L: Dispersion coefficient ($L^2 T^{-1}$)

u: Mean velocity of the flow ($L T^{-1}$)

S: External sources or sink ($M T^{-1}$)

The model also simulates the following processes: algal growth, phosphorus and nitrogen cycles, coliforms evolution, atmospheric reaeration and pesticide fate. The relevant simulated variables for APS determination are: organic nitrogen (*N-org*), ammonia (NH_3), nitrites (NO_2), nitrates (NO_3), organic phosphorus (*P-org*), dissolved phosphorus (*P-dis*), and up to three pesticides simultaneously. Transformations of those variables are modeled by first order kinetics described in Brown and Barnwell (1987). Organic farming practices influence inputs of nutrients and pesticides into the water bodies, as simulated by the land and pesticide transport models, but they have no further influence on the processes simulated by the water quality model. The water quality model is therefore not influenced by organic farming, except for the potential modification of inputs simulated by the preceding models.

5 ENVIRONMENTAL IMPACT OF ORGANIC FARMING

Conacher and Conacher (1998) made a review of the environmental effects associated with organic farming. Such effects comprise real, or potentially, beneficial effects to: the soil (including changes to soil physical, biological and chemical properties, soil nutrient, soil acidity), pest and diseases incidence, plant and animal quality, erosion and runoff, recycling of organic waste, reduced use of synthetic chemicals, the ecological systems. Some of those environmental effects will be briefly discussed, with emphasis on the aspects related to water quality that can influence APSs. Among the environmental effects presented, there is the increased risk of nutrient imbalance due to (i) reduced availability of organic manure, (ii) the precise timing of operation that is required in order to make the nutrient, tied up in organic or insoluble forms within the soil matrix, available for plant uptake. Increasing soil acidity by incorporating plant residues and animal manure can also be problematic in some regions.

5.1 Reduction of erosion

The build up of soil organic matter and maintenance of a protective surface cover under organic systems favour a reduction in soil loss (Crosson, 1981; Papendick and Elliot, 1984, in Conacher and Conacher, 1998). Auerswald *et al*. (2003) used the Universal Soil Loss Equation (USLE) to make a statistical evaluation of soil erosion for 2056 district in Bavaria, comparing the organic and conventional systems. They estimated that there was an average of about 15% less erosion on organic arable land than for conventional farming due to the larger area of grass under the organic system. Moreover, they pointed out that organic farms are more often located in areas that are vulnerable to erosion than conventional farms.

5.2 Reduced use of synthetic chemicals

The approach to insects, weeds and diseases control under organic systems is an integrated and preventive one. The prohibition of pesticides and synthetic fertilizers causes less disruption of natural habitats, increases incidence of beneficial organisms, reduces toxic residues, and lower costs of chemical inputs and remediation (Conacher and Conacher, 1998). Organic farming practices have also been found to reduce the incidence of pests and diseases through changes to organism physiology, metabolism and habitat (Cook, 1986; Smal and McDonald, 1992; Sivapalan *et al*., 1993; Hedges, 1996; Tesoriero *et al*., 1996, in Conacher and Conacher, 1998).

5.3 Soil physical, biological and chemical properties

The addition of organic matter to the soil, with good management practices, can improve soil structure, stability and cohesion. It can result in a reduced bulk density and a better aeration. Cation exchange capacity and soil water balance are also improved. However, those improvements are conditional to soil type, climate, local conditions, past land use, types and rates of soil amendments and/or practices. The adverse effects on soil animal diversity and abundance associated with the use of chemical fertilizers and pesticides on conventional farms is reversed under the organic systems. This can result in an increased in soil biomass, biological abundance, diversity and activity (Conacher and Conacher, 1998).

There is a close relationship between the organic matter content and the nutrient status of soils. Long term experiments have shown that crop rotations, typically used in organic farming, are capable of increasing the soil organic carbon content by 13-28% compare to conventional arable farming (Smith *et al*., 1997). Arden-Clarke and Hodges (1988) stated that physical and biological changes in soil properties under organic farming systems improve the soil's chemical status with regards to nutrients and their availability.

Atmospheric nitrogen (N_2) fixation can be a very important nitrogen input in organic farming systems. The N_2 fixation is mainly influenced by the inorganic nitrogen content in the soil, the soil water content, the soil temperature, and the legume species (Hansen *et al*., 2000). The conversion from conventional to organic arable farming implies a shift from mineral to organic fertilizers, in which high levels of mineral fertilizer inputs are replaced by manure amendments and the introduction of green manure in crop rotations. Furthermore, organic farms maintain a higher proportion of permanent grassland, incorporate more straw into soils and make more efficient use of catch crop than conventional farms (Knudsen *et al*., 2006).

The nitrogen balance model used by Hansen *et al*. (2000) show an average total nitrogen input to the organic systems lower (104–216 kg $N \cdot ha^{-1} \cdot yr^{-1}$) than to the conventional farming systems (146–311 kg $N \cdot ha^{-1} \cdot year^{-1}$). The N-balances for both systems showed a surplus of nitrogen into the root zone (60 to 143 kg $N \cdot ha^{-1} \cdot yr^{-1}$ for the organic system, and 25 to 155 kg $N \cdot ha^{-1} \cdot yr^{-1}$ for the conventional system). Figure 5.1 illustrate the nutrient flows that may occur on an organic farm.

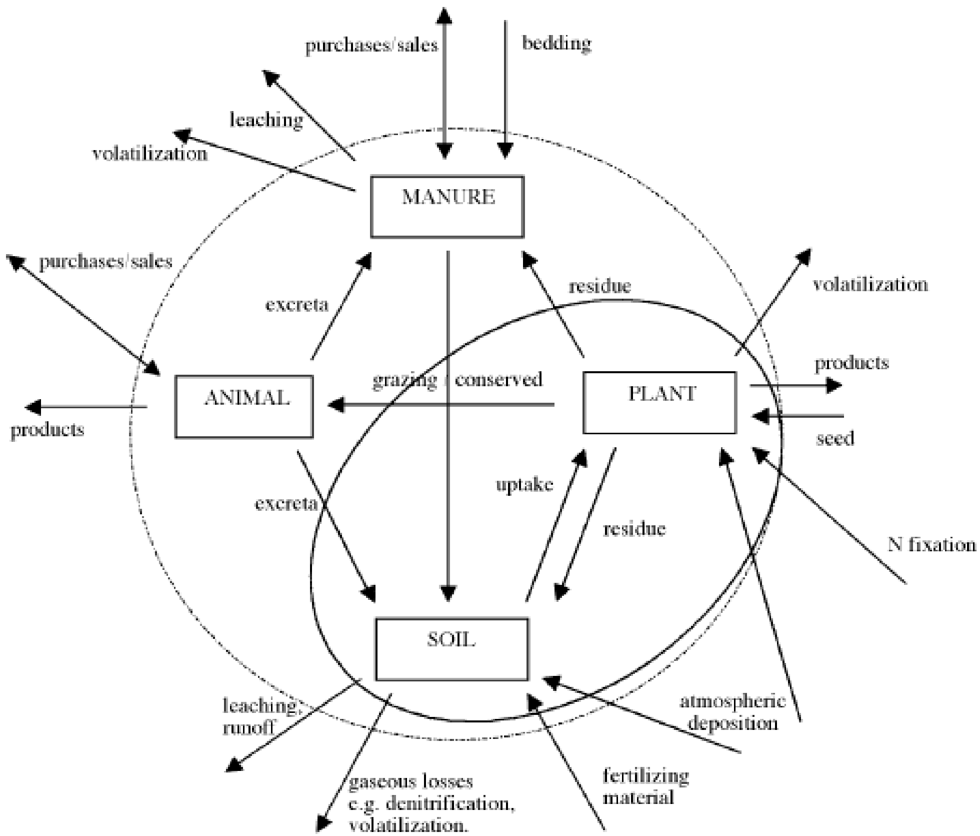

Figure 5-1 Representation of nurient flows that may occur on an organic farm (from Watson *et al.*, 2002)

Watson *et al*. (2002) reviewed 88 nutrient budgets of organic farms in nine temperate countries. All the nitrogen budgets showed an N surplus (average 83.2 kg $N \cdot ha^{-1} \cdot yr^{-1}$). The efficiency of N use, defined as outputs/inputs, was largest (0.9) in arable farms, and lowest (0.2) in beef farm system. The P budget showed a surplus (average 3.6 kg $P \cdot ha^{-1} \cdot yr^{-1}$). The estimation of N fixation and quantities of nutrients in manures may however introduce significant errors in nutrient budgets (Watson *et al*., 2002).

Ryan *et al*. (1994, in Conacher and Conacher, 1998) report that levels of mycorrhizal colonization, which are important for the efficiency of phosphorus and other nutrients uptake under low soil nutrient conditions (Wild, 1993; in Conacher and Conacher, 1998), were greater under organic treatment than under the conventional treatment.

5.4 Nutrient leaching

A few studies compared nutrient leaching from organic and conventional farming systems. N leaching from organic farming systems is sometimes lower than from conventional systems, but the difference is not always significant (Korsaeth, 2008; Aronsson *et al*., 2007; Stark *et al*., 2006; Stopes *et al*., 2002). Knudsen *et al*. (2006) reported lower leaching from organic mixed dairy farms than for conventional systems, but it was comparable for both systems when considering arable farms. Hansen *et al*. (2000) also reported a lower N leaching potential for organic mixed dairy/beef farms, and organic arable crops on sandy soils than from the same conventional systems in Denmark. However, it was still uncertain whether the N leaching is smaller or larger from organic arable crop production systems on a loamy soil, and organic pig production on loamy and sandy soils, than from the same conventional systems. Modelled N leaching varied from 19 to 30 kg $N \cdot ha^{-1} \cdot yr^{-1}$ on loamy soils to 36–65 kg $N \cdot ha^{-1} \cdot yr^{-1}$ on sandy soils under organic farming. Comparable leaching from both systems, in a range between 66 and 87 kg $N \cdot ha^{-1}$ over the October-March period, was also reported by De Neve *et al*. (2003), except for conventional pasture system which had a smaller lost (35 kg $N \cdot ha^{-1}$) and the conventional cauliflower system which had very large losses (293 kg $N \cdot ha^{-1}$). N leaching potential risk from organic and low N-input systems was reported by Poudel *et al*. (2002), to be lower than for conventional systems in northern California due to lower mineralization rates, but it was found to be very similar on average by

Kristensen *et al*. (1994) for organic and conventional farms using manure. However, that last study also reported that conventional farms not using manure had a lower N leaching risk than the two aforementioned systems. Torstensson *et al*. (2006) also found that average N leaching loss was less important from a conventional system with a cover crop (25 kg $N \cdot ha^{-1} \cdot yr^{-1}$) compare to an organic system with (39 kg $N \cdot ha^{-1} \cdot yr^{-1}$) or without (34 kg $N \cdot ha^{-1} \cdot yr^{-1}$) animal manure, or a conventional system without cover crop (38 kg $N \cdot ha^{-1} \cdot yr^{-1}$). Sylvasalo *et al*. (2006) could not confirm the environmental advantage of the organic system over the conventional system with respect to N leaching in sandy soils.

The difference between the vulnerability to N-leaching of organic versus conventional systems was sometimes attributed to crop rotation and green manure (Stark *et al*., 2006), and to lower N input (Knudsen *et al*., 2006; Hansen *et al*., 2000). Cuttle and Jarvis (1995) also mentioned the potential impact of differences in the organic matter content and biological activity of organically and conventionally managed soils. Independently of the agricultural system, N leaching occurs when there is a large amount of soluble inorganic N in the soil at times of the year when low evapotranspiration and/or high precipitation leads to percolation through the root zone (Hansen *et al*., 2000). Vulnerability to leaching is affected by the choice of crop rotation (Thomsen *et al*., 1993), and more particularly by the use of catch crop (Hansen *et al*., 2000; Knudsen *et al*., 2006), the soil type, and the level of soil organic matter (Knudsen *et al*., 2006). It is larger in sandy soils with a high level of soil organic matter and no catch crops (Knudsen *et al*., 2006). Evaluation of different management scenarios by Knudsen *et al*. (2006) suggest that the increased use of catch crops was the single most efficient farming practice for reducing N leaching loss: by approximately 9 kg $N \cdot ha^{-1} \cdot yr^{-1}$ for organic farms and 7 kg $N \cdot ha^{-1} \cdot yr^{-1}$ for conventional farms. The amounts of fertilizer or manure applications, and the timing of applications, also have significant effects on the leaching of nitrate, particularly if the application raises the level of inorganic nitrogen in the soil when there is percolation from the root zone (Knudsen *et al*., 2006).

Aronson *et al*. (2007) reported an average annual P leaching that showed a greater variation than N leaching, and that was significantly greater in an organic system without animal manure (0.81 kg $P \cdot ha^{-1} \cdot yr^{-1}$), in which green manure crops were used for N supply, than in conventional cropping system with cereal and application of mineral fertilizer (0.36 kg $P \cdot ha^{-1} \cdot yr^{-1}$) or in organic system where cattle slurry was applied (0.41 kg $P \cdot ha^{-1} \cdot yr^{-1}$). Torstensson *et al*. (2006) reported P leaching loads that were small (<0.25 kg $P \cdot ha^{-1} \cdot yr^{-1}$) regardless of the agricultural system.

5.5 Summary

Following this review, it can be concluded that a conversion from a conventional farming system to an organic farming system can affect water quality by: (i) potentially reducing sediment loads due to soil erosion by an increased use of cover crops; (ii) reducing total pesticide load in watercourses since pesticides are prohibited by organic standards; (iii) affecting nutrient cycles and nutrient availability to leaching by using green manure and catch crops instead of synthetic fertilizers. It is however uncertain whether the changes occurring in the nutrient cycles are increasing or lowering nutrient exports by leaching and runoff to the surface water.

6 LITTERATURE SEARCH ON ORGANIC FARMING MODELLING WITH REGARDS TO APS

A literature search was conducted in order to identify models that have been used so far to simulate the impact of organic farming practices on surface water quality, or on the processes that affect surface water quality. The search was performed with the Boolean expression:

organic AND (farm* OR agri*) AND model**

to be found in the title of documents covered by the following databases and search engines:

1. Web of Science (1989 - today)
2. Scopus (1823 - today)
3. Agricola (15th century - today)
4. Water Resources Worldwide (1967 - today)
5. World Wide Science.org
6. Google Scholar

Complementary literature regarding environmental benefits of organic farming, and type of organic practices, was found by searching the following expressions in combination to the "*organic* AND (farm* OR agri*)*" condition:

conventional, leach*, review**

An important fraction of the models dealing with organic agriculture are devoted to evaluate the feasibility or the economic impact, at scales ranging from the farm to the whole state, of converting from the conventional to the organic farming system.

Considerable modelling effort was also made in order to assess the impact of different policies regarding organic agriculture on economic and environmental aspects. Berentsen and Huirne (2005) reviewed several of those models. More recently, models have also been used to compare the energy efficiency and the impact of agricultural farming on global environmental issues like carbon sequestration and greenhouse gas emission (Pelletier *et al*., 2008; Kusterman *et al*., 2008; Olesen *et al*., 2006; Foereid and Hogh-Jensen, 2004; Dalggard *et al*., 2001).

More relevant to the present review, with regards to APSs, are the models that have been used for assessing impact, at the farm level, of organic farming on erosion, pesticide, and nutrient exportations to surface water. Of the reviewed studies, only Auerswald *et al*. (2003) modeled the effect of organic farming on erosion, at the regional scale, with the USLE equation. Since pesticides are prohibited in organic farming systems, pesticide exports from organic farms are not an issue that has been examined by the scientific community.

Most of the examined literature was related to nutrient fluxes modeling. Some of the examined models were intended to be management tools at the farm scale. Such are MANMOD (UK Department for Environmental, Food and Rural Affair, 2001) and MANNER (Chambers *et al*., 1999). Those modeling tools can compare different techniques of manure management in order to minimize nutrient leaching, ammonia volatilization and nitrous oxide emission. They require little information as input, relying on databases built with field measurement and scientific literature data. ROTOR

(Bachinger and Zander, 2006) is another management tool designed to optimize crop rotation with regard to nutrient balance, nitrate leaching, weed infestation risks, and economic performances. A simple empirical equation, depending on percolation, soil clay content, average nitrogen input and crop sequence, was used by Hansen *et al*. (2000) to model nitrogen leaching. Finally, four farm-scale nutrient dynamic simulation models were examined. DAISY (Hansen *et al*., 1991) was employed by Müller *et al*. (2006), to study how catch crops affected nitrogen dynamics in organic farming systems. It was also used by Jensen *et al*. (1999) to simulate plant production and N fluxes in organic farming systems. NDICEA (Koopmans and Bokhorst, 2002) was used to estimate how crop rotations and manure applications affect the amount of mineral nitrogen in different phases of a crop rotation. FASSET (Berntsen *et al*., 2003) was applied by Knudsen *et al*. (2006) to estimate N leaching losses on organic and conventional arable farms in Denmark. The FARMFLOW model was used by Modin-Edman *et al*. (2006) to compare the stocks, flows and resulting balances of P in organic and conventional dairy farms. The GLEAMS model has also been utilised by Pacini *et al*. (2003) to evaluate sustainability of organic, integrated, and conventional farming systems, but details on the modeling exercise have not yet been published. The next sections summarize the results obtained in the aforementioned studies.

6.1 USLE (Auerswald *et al*., 2003)

Only one reviewed article compared the erosion from organic and conventional farming systems. Auerswald *et al*. (2003) used the Universal Soil Loss Equation (USLE) to make a statistical evaluation of soil erosion for 2056 districts in Bavaria, comparing the two systems. On average, about 15% less erosion on arable land was predicted for organic agriculture than for conventional farming due to the larger area of grass, although organic farms occupy areas that are more often prone to erosion than conventional farming. USLE predict long term average, annual soil loss from the multiplication of six complex terms:

$$A = R\,K\,L\,S\,C\,P \tag{6.1}$$

Where;

- A: Long-term average annual soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$);
- R: Rainfall and runoff erosivity ($N \cdot h^{-1} \cdot yr^{-1}$);
- K: Soil erodibility ($t \cdot h \cdot ha^{-1} \cdot N^{-1}$);
- L,S: Dimensionless topography factors quantifying the influences of the watershed area and watershed curvature;
- C: Dimensionless factor quantifying the influence of the cropping system;
- P: Dimensionless factor quantifying the influence of permanent erosion control measures like terracing and contouring.

The C factor quantifies the influence of cropping, and is thus the main factor that distinguishes organic from conventional systems. It is computed from the combination of a soil loss ratio (SLR) with an erosivity index (EI) (Wischmeier and Smith, 1978). The EI quantifies the seasonal distribution of rainfall erosivity. The SLR quantifies the susceptibility of the soil surface relative to the conditions that occur in a freshly prepared seedbed, which is thus considered a standard. The SLR mainly depends on tillage and soil cover.

The *C* factor must be computed as a long term average for complete rotations because there is often a period between two main crops, that may last for several months, where considerable erosion may occur but cannot be assigned either to the previous or to the following crop. Also, some carry-over effects may exist, by which the previous crop influences the extent of erosion during following years. This is especially true in grass-based rotations. Sod-forming crops like clover-grass are known to stabilize the soil. This decreases soil loss up to two years after the sod has been ploughed as compared to an otherwise identical system without sod (Wischmeier and Smith 1978).

The *C* factor was estimated by Auerswald *et al*. (2003) using simple parameters with the following equation, valid for both organic and conventional farming systems:

$$C = \{[830-15.8(G+M+S) + 0.082\,(G+M+S)^2]\,(1-0.03S) + 0.1S - 0.5M + 27\}/1000 \qquad (6.2)$$

Where:

- *G*: Percentage of small grain (including oil seeds);
- *M*: Percentage of row crops planted in mulch tillage (planting of row crops into a mulch cover crated by the cultivation of cover crops, which are either frozen down during winter or chemically killed prior to row crop sowing or planting);
- *S*: Percentage of sod-forming crops

When the calculated *C* factor is less than 0.01, its value is set to 0.01, and when it exceeds 0.45, it is set to 0.45.

6.2 MANMOD and MANNER models

MANMOD is an iconographic-based model representation of the pathway followed by manure in an individual organic farm. The different stages are taken into account by the model as a sequence of node-component (manure source, housing system, hard-standing area, storage system, applicator, soil-type, hydrologic environment, import and export) where the output, the losses, and the balance of nutrients (N, P and K) are computed on a monthly basis. MANMOD maintains a running balance of those nutrients through each component of the system for both "liquid" and "solid" fractions of the manure by updating volume or mass, percentage of dry matter, and nutrient concentration. Default values for the initial monthly volumes, nutrient concentrations and dry matter are extracted from a database containing records of urine and faeces for each livestock type (not published). Dynamics in the components are simulated by simple empirical equations. Lack of detailed measurements did not allow to thoroughly testing the validity of the model (UK Department for Environmental, Food and Rural Affair, 2001).

MANMOD was designed to be used in combination with the MANure Nitrogen Evaluation Routine (MANNER) to evaluate gaseous emission, nitrate leaching, and nitrate availability following spreading of organic manure in the field. Type and rate of application of manure are required as input. Default values for dry matter content, total N, and readily available N, also needed as input, are associated with 17 different types of manure (appendix B). Application date, delay before incorporation, soil texture, date of end of drainage and total rainfall are the other needed information. Volatilization is simulated as a function of *t*, the time between manure application and incorporation, of

N_{max}, a maximum NH_3 volatilization loss as t approaches infinity, and of a K_m value representing the time when the cumulative NH_3 volatilization reached $0.5 \cdot N_{max}$. N_{max} and K_m values were derived for different manure types. Denitrification and immobilisation are not simulated. Mineralization is simply calculated by multiplying the amount of organic N in the manure by a factor depending on the type and time of application. Leaching is calculated by multiplying the readily available N by the effective rainfall divided by the topsoil volumetric moisture content minus a constant. Good agreement was found when comparing the model prediction to experimental data. A more detailed description of the model and the equations used are included in Appendix B.

6.3 ROTOR model (Bachinger and Zander, 2007)

ROTOR is a tool designed to generate and evaluate site-specific crop rotations for organic farming systems in central Europe. A relational database is used to assemble a set of annual crop production activities (CPAs) from single site and crop specific field operations. More than one CPA is associated to each crop depending on the preceding crop, and the following field operations (ploughing or non-inverting tillage, undersowing crops, using catch crops, manuring, straw harvesting, and mechanical weed control). Ruled-based assessment modules are then used to evaluate yield, economic performance, N balance, nitrate leaching, and weed infestation risks. All possible sequences of CPAs are then linked to a 3-8 year preliminary crop rotations according to farm type (cash crop farm with legume grass used as set-aside, no manuring, no straw harvesting; mixed farm with legume grass forage production) and soil quality (CPAs are described for four different production levels depending on soil quality). N balance and N leaching risk are quantified by using a set of algorithms derived from literature, experimental data, on-farm research and expert knowledge (Appendix C). This allows for the assessment of N removal, N_2-fixation, and N losses through nitrate leaching and NH_3-volatilization out of mulched biomass, according to site characteristics and preceding crop category. The capability of different catch crops undersown in main crops or stubble seeded to reduce NO_3- leaching is included. The sum of the atmospheric deposition and the non-symbiotic N_2-fixation is assumed to be equal to the denitrification losses and therefore these processes are not calculated. A more detailed model description and its equations are included in Appendix C.

6.4 HANSEN *et al*. (2000) equation

The empirical model used by Hansen *et al*. (2000) was adapted from Simmelsgaard (1998):

$$L = \exp(1.136 - 0.0628 clay + 0.00565 N + crop) P^{0.416} \qquad (6.3)$$

Where:

- L: N leaching;
- $clay$: clay content (%) in the 0-25 cm depth;
- N: average N input ($N = N_{manure} + N_{fertilizer} + N_{fixation}$);
- $crop$: parameter estimate related to the summer crop and the following winter crop;
- P: percolation in $mm \cdot yr^{-1}$

No value for the *crop* parameter are given in Hansen *et al*.(2000), however, different crop yields in Denmark on loamy and sandy soils, as well as N balance and modelled N-leaching from organic and conventional arable crop farms, pig farms, dairy/beef farms are presented (Appendix D).

6.5 DAISY model (Hansen *et al.*, 1991)

DAISY is a deterministic model that simulates water, energy, C and N-fluxes in a one-dimensional soil-plant-atmosphere system. Jensen *et al*. (1999) presented preliminary modelling results on N fluxes in organic farming systems and outlined the need to develop a robust crop module for grass-clover mixtures used as green manure. According to Müller *et al*. (2006), DAISY was able to simulate soil mineral N and soil microbial biomass N after soil incorporation of catch crop plant residues to some extent only. Some processes needed further investigation: (1) soil-tillage induced mobilisation of organic material including considerable amounts of organic N; (2) winter killing of sensitive plant species and varieties; (3) decomposition of plant residues at the soil surface; (4) decomposition of easily decomposable plant residues at low temperatures, both with respect to a temperature modifier function and to the linkage of C an N turnover; (5) reliable criteria for the subdivision of green plant residues into an easily decomposable pool and a more recalcitrant pool.

The model includes a hydrological model (with a submodel for soil water dynamics), a soil temperature model, a soil nitrogen model (with a submodel for soil organic matter dynamics), a crop model (with a submodel for N uptake).

The soil part of the model has a one-dimensional vertical structure. The soil profile is divided into layers on the basis of physical and chemical soil characteristics. The soil N model takes into account net mineralization, nitrification, denitrification, uptake by plants and leaching from the root zone.

Degradation of soil organic matter is considered to be the determining step governing mineralization. Organic matter in the soil is conceptually divided into three main pools (Appendix E): dead native soil organic matter (SOM), microbial biomass (BOM) and added organic matter (AOM). Each main pool of organic matter is subdivided into two or three subpools characterized by a particular C to N ratio and by a particular turnover time. The rate of decomposition of SOM is simulated by first-order reaction kinetics. The BOM in the soil usually accounts for less than 3% of the total soil organic carbon. Simulation of microbial biomass turnover is based on growth efficiency, maintenance, respiration, and death rate coefficients. The added organic matter (AOM_0) is organic fertilizer such as farmyard manure, slurry, green crop manure, or crop residues left in the field after harvest. The added organic matter is allocated to subpools AOM_1, AOM_2 and SOM_2. Subpool AOM_1 is a substrate for both BOM_1 and BOM_2, and decomposes slowly, while AOM_2 which is easily decomposable is a substrate for BOM_2 only. The rates of decomposition of AOM_1 and AOM_2 are simulated by first-order reaction kinetics.

The considered abiotic factors influencing the carbon turnover are soil temperature and soil water status, and in the case of subpools SOM_1, SOM_2, BOM_1, also clay content.

The abiotic functions (Appendix E) adopted were derived from various sources in the literature.

Nitrification is influenced by soil temperature and soil water status. The abiotic functions adopted for nitrification were derived from various sources in the literature (Appendix E).

Denitrification is modelled by defining a potential denitrification rate (*i.e.*, the denitrification rate under complete anaerobic conditions). The potential denitrification rate is assumed to be related to soil temperature (by the same function used for mineralization; Appendix E), CO_2 evolution rate, and an empirical constant. Under partly anaerobic conditions, the potential denitrification rate is adjusted according to the soil water saturation (Appendix E).

N uptake model, for ammonium and nitrate, is based on the concept of a potential N demand simulated by the crop model, and the availability of N for plant uptake. N uptake equals the N flux toward the root surface, which is calculate by mass flow and diffusion equations.

Vertical movement of nitrogen in the soil is modelled by solving the convection-dispersion equation.

6.6 NDICEA model (Koopmans and Bokhorst, 2002)

The Nitrogen Dynamics in Crop rotations in Ecological Agriculture (NDICEA) model was developed to estimate how crop rotations and manure applications affect the amount of mineral nitrogen in different phases of a crop rotation. It was tested on eight (8) organic farms and research sites and results fitted observed mineral N for the top 30 cm of the soil with a modeling efficiency (ME) of 0.4 and a coefficient of determination (r) of 0.5. The performance of the model was limited regarding the prediction of N level in the lower soil layer, and the authors have some reserves on its ability to adequately predict N leaching losses.

The model consists of four major modules: water balance, organic matter balance, crop growth, and N balance. It uses a weekly time step. The modeled soil profile in the root zone is divided in two layers. The top layer (0-30 cm) is the layer where mixing of the soil takes place through cultivation. Manure and fertiliser additions are applied and mixed to that layer. Storage of water and nutrient can also take place in the sub-layer (30-60 cm) if leaching occurs from the upper layer. Inorganic N is transported with the water down the soil profile, depending on a N leaching factor. Nitrogen that leaches below the rooting depth is considered lost.

The core of the model is the decomposition module in which the mineralization process is described. Mineralization is calculated for each successive application of organic matter, and according to the type and quantity of that organic matter. For each type of organic matter the C: N ratio and the apparent initial age (ranging from 1 for green matter to 24 years old for soil organic matter) are used as input. Corrections are applied for soil temperature, soil moisture, texture and pH. The undecomposed part of the organic matter contributes to the soil organic matter pool. The quantity of soil organic matter in the model is based on an initial soil analysis. N mineralization is calculated based on the assimilation/dissimilation ratio of the soil organisms, the carbon/nitrogen ratio of soil organisms, the type of substrate and the rate of organic matter decomposition.

The nitrogen balance is calculated from the crop growth module and the water and organic matter balances. It includes N input fluxes such as mineralization, atmospheric deposition, nitrification, fertilizer application, N_2 fixation and N outputs such as crop uptake, leaching and denitrification. NH_4 volatilization and water logging are not part of the model. N fluxes in the soil are associated with the water fluxes. N leaching is based on an excess of water, the amount of mineral N in the soil and soil physical properties. It is estimated to be the sum of matrix outflow and bypass flux of nitrogen. Denitrification is calculated in the model as a potential denitrification, corrected for soil moisture and mineral N content in the soil.

Crop uptake depends on crop uptake curves and actual yields. Crop N uptake is calculated based on N concentration in the crops (product, residues and roots), water uptake, soil moisture content and N concentration in the soil water. N_2 fixation of legumes is estimated from the potential N-fixation and the mineral N content of the soil. Water uptake by a crop is governed by evaporative demand, crop morphology, ground coverage and soil moisture content. Necessary input data for the model are summarised in table 6.1. Major outputs consist of expected mineral N in the soil layers, N uptake of the crops and levels of organic matter in the soil.

Table 6-1 Input data for the NDICEA model

Field	Input
Environment	Temperature (ºC), rainfall (mm), evapotranspiration (mm)
Soil	Texture, organic matter (%), pH, groundwater table (time and depth of highest and lowest levels)
Crops	Yield (kg), dry matter ($kg{\cdot}ha^{-1}$), nitrogen conc. (%), date of sowing, full cover, ripening, harvest (week)
Organic manure	Application rate ($kg{\cdot}ha^{-1}$), dry matter (%), organic matter (%), N conc. (%)

6.7 FASSET model (Berntsen *et al.*, 2006)

The Farm ASSEssment tool (FASSET) is a whole-farm dynamic simulation model with two major components: a planning module, and a simulation module. It was used by Berntsen *et al*. (2006) to evaluate the environmental and economic consequences of implementing different N taxes on Danish farms. The field module of the program, which consists of crop and soil sub-modules to estimate N leaching and soil N changes on arable farms (Appendix F), was used by Knudsen *et al*. (2006) to estimate N leaching losses for organic and conventional farming in Denmark. Representative characteristics and area-based averages of organic and conventional farms of Demark (Appendix F) were generalized on two 10-year crop rotations, one for each system (Appendix F). The organic crop rotation has a high proportion of spring cereals and the proportion of grass/clover (green manure) is 0.2, while the conventional crop rotation uses more cereals, primarily winter cereals. These crop rotations were used as input for FASSET, along with management details. The effect of different management practices on N leaching loss was evaluated by constructing scenarios like the use of catch crops, the incorporation of straw, different fertilization level, and different proportions of grass/clover in the crop rotation for the organic system. N balances and N leaching loss for different soil types obtained with the FASSET model are presented in Appendix F for references.

6.8 FARMFLOW model (Modin-Edman *et al.*, 2007)

FARMFLOW is a model developed to simulate dynamic P mass-balance on conventional and organic Swedish dairy farms. Simulations for the two systems during six crop rotations (36 years) resulted in higher proportion of internal P flows for organic farm, whereas the conventional system relies more on imports of P in feed and mineral fertilizers. In both management systems, the crop rotation caused large temporal and spatial variation in the application of manure P to soil system. The simulations also showed that the annual P accumulation/depletion could not explain the field specific contribution to the total amount of P lost from the fields in the crop rotation. Authors concluded, regarding P losses, that many processes are involved and that a rather detailed parameterization would be needed regarding soil hydrology, soil physical properties and P status in order to mimic the losses more accurately. A more detailed model description, and equations used, as well as parameters for the organic and conventional management practices at the Öjebyn experimental farm are included in Appendix G.

6.9 Summary

Only one of the examined model simulated soil erosion on organic farms at the regional scale. None of the models simulated pesticide losses from organic farms since pesticides are prohibited by organic farming standards. Although many models have been used to simulate nutrient dynamics (Drewry *et al*., 2006; Hertel *et al*., 2006; Prakasa Rao and Puttana, 2006; Lewis and McGechan, 2002; Chambers *et al*., 1999; Wu and McGechan, 1998) only the models used within an organic agriculture context were considered for the present review. Those models aimed to simulate nutrient leaching in a context of nutrient balance optimization for agricultural yield. Nutrient leaching out of the root zone was thus computed as a global loss, and the fraction of leached nutrient that reached the surface water (which can influence APSs), as opposed to the fraction that leach out of the root zone without necessarily reaching the watercourses, has not been explicitly simulated with the reviewed models. Also, none of the models accounted for runoff nutrient losses to watercourses. In Denmark, the average nitrate leaching from sandy catchment during 1989-1996 amounted to 123 kg $N \cdot ha^{-1} \cdot yr^{-1}$ and for loamy catchment it was 72 kg $N \cdot ha^{-1} \cdot yr^{-1}$ (Grant *et al*., 1997 in Hansen *et al*., 2000). The nitrogen load in watercourses was 12 kg $N \cdot ha^{-1} \cdot yr^{-1}$ in sandy catchment and 27 kg $N \cdot ha^{-1} \cdot yr^{-1}$ in loamy catchment. Transported nutrient to surface water thus seems to depend not only on total leaching out of the root zone, but as expected on soil type.

7 MODELLING THE ORGANIC FARMING SYSTEM WITH GIBSI

GIBSI is an integrated model that can assess the impact of different scenarios on surface water quality at different locations on a watershed. It is currently set to model conventional farming systems, but since the modelling approach is process-based, it could be adapted to simulate the impact of organic farming systems. Erosion, pesticide uses, nutrient balances and nutrient transport can differ when considering the impact of organic versus conventional farming systems on surface water quality. It will now be examined, with the insight from the literature reviewed in the preceding sections, how those elements can be simulated within GIBSI.

7.1 Modelling soil erosion

The modelling of erosion on an organic farming system with GIBSI will depend on the amount of information available. Since the erosion is simulated with RUSLE in GIBSI, equation 6.2 can be used to calculate *C* factor if the proportion of small grain, row crop, and sod-forming crops on the watershed is known. *C* factors corresponding to a "typical organic crop rotation" on the modelled watershed can also be found, or adapted from the *C* factors given by Duchemin (2000) or Wall *et al*. (2002). The average *C* factor is expected to be lower for the organic farming system, when compared to the conventional, since green manure is used more in crop rotation systems.

Another approach, if required information to compute *C* factor is not available, would be to apply a 15% reduction (based on the average results from Auerswald *et al*., 2003) on the daily erosion computed with the conventional *C* factors used for conventional farming crop rotation.

7.2 Modelling pesticide use

Since all organic standards prohibit the use of pesticides, none of the surveyed literature specifically dealt with the modelling of pesticide transport on organic farms. In Canada, all pesticides, except pyrethrum, for mushroom production, and some domestic formulations of rotenone, are excluded from the Organic Production Systems Permitted Substances List (CAN/CGSB-32.311). Therefore, no pesticide application should be simulated on the organic crops. If one considers APS at the watershed level, the benefits on pesticide load reduction into the river will grow proportionally to the fraction of the watershed agricultural area under the organic farming system.

7.3 Modelling nutrient balance and transport

Most of the reviewed articles regarded nutrient balance modelling of organic farms. Nutrient balance is of primary concern to the organic farmers since no synthetic fertilizers are allowed to replenish the soil nutrient pools after the crop, or animal product, export. GIBSI currently simulates the main processes of N and P cycles (Lasbleis *et al*., 2008). Adaptation to simulate the organic farming system would mainly be made by changing input parameters. Nutrient import to the soil by organic or green manure, the use of green manure and catch crops in the rotations, and the crop and nutrient yields are the main elements that should be adapted.

Nutrient runoff has not been simulated by the reviewed model introduced in Chapter 6. GIBSI can simulate runoff for the conventional farming system (Lasbleis *et al*., 2008). It can be assumed that no special adaptation would be required for modeling the runoff from organic farming systems, beside the previously cited elements that will affect the nutrient pools available for transportation by runoff.

7.3.1 Nutrient import by organic or green manure

Contrary to some European regulations, Canadian standards do not limit the quantity of imported nutrient by organic manure or permitted mineral fertilizers. However, the obligation to use manure produced according to organic standards can limit its availability, and indirectly limit nutrient import on organic farms. Nine fertilizing scenarios are available in GIBSI to model the amount of nutrient imported during fertilization (Lasbleis *et al*., 2008). Two of those scenarios are coherent with the organic farming systems: (i) the scenario that applied manure from the farm and (ii) the scenario that applied manure from the farm and fill in P deficits with mineral fertilizers. Since N cannot be added via mineral fertilizers according to Canadian standards, all the scenarios that fill in N deficits with synthetic or mineral fertilizers are not adequate for the purpose of simulating an organic farming system.

Also, Modin-Edman *et al*. (2007) suggest that the livestock diet composition of the organic system involves a higher proportion of silage compared the conventional farming systems that rely more on barley, concentrates and minerals. That would cause a lower nutrient import from an equal quantity of manure produced according to organic standards when compared to manure produced in a conventional system. Some average nutrient content of permitted soil amendments, mature compost, and different compositions of fresh manure, as well as C: N ratio of compost materials from the Organic Field Crop Handbook (Wallace, 2001) have been included in Appendices H and I as reference. N content of different types of manure from Chambers *et al*. (1999) can also be found in Appendix B. Some of those values could be integrated in the GIBSI database to take into account the nutrient import differences between organic manure and conventional manure. Another approach would be to calculate an average factor to convert the conventional manure nutrient contents that presently exist in the GIBSI database into “adjusted” organic manure nutrient contents. Data from table 2 in Modin-Edman *et al*. (2007) (Appendix G), or Table 8 in Knudsen *et al*. (2006) (Appendix F) could be used to compute such factor.

Since no synthetic fertilizer is allowed, it is important to take into account the effect of green manure in the simulation of nutrient balance for the organic farming system. GIBSI does not currently compute the N import from such crop. N import according to the type of green manure should be included in the GIBSI database. Such values are given in the Organic Field Crop Handbook (Wallace, 2001) (Appendix J).

7.3.2 Crop rotation, green manure and catch crop

Crop rotation can already be modelled by GIBSI. As seen in section 3.2, organic crop rotations vary according to the specific conditions of the farm. To build a "representative crop rotation" that can be used on a given watershed, it is recommended to contact local organic farming advisors, or certification bodies. Simply adding a green manure crop in the conventional farm rotation may be an acceptable estimation at the watershed scale if the required information is not available.

In the organic system, green manure and catch crop are essential to replenish the soil nutrient pools and limit nutrient leaching out of the root zone. GIBSI already have a routine that manage incorporation to the soil and transformation of nutrients from crop residues (Lasbleis *et al*., 2008). However, due to the larger quantities of nutrients involved when dealing with green manure and catch crop, and due to the importance of timing of the different processes (incorporation of the residues into the soil, mineralization, nutrient uptake of the following crop) and the leaching that can occur during those processes, some validation and calibration of the model regarding that particular case might be necessary.

7.3.3 Crop and nutrient yields

Lower livestock population, livestock products, or crop yields are usually reported from the organic systems in Canada (Badgley *et al*., 2002) comparatively to the conventional systems. Accordingly, lower nutrient export rates must be modelled in order to have a correct nutrient balance. Major Canadian crop yield nutrients are given in the Organic

Field Crop Handbook (Wallace, 2001). Those values could be incorporated into the GIBSI database. Another possible way to model the organic crop and nutrient yields would be to apply an average ratio to the conventional system yield values already in the database. Pelletier *et al*. (2008), based on data reported by Badgley *et al*. (2002), have evaluated that Canadian organic yields of canola, corn, soy, and wheat were on average 90%, 95%, 100%, and 90% those of conventional yields, respectively.

8 CONCLUSION

A conversion from a conventional farming system to an organic farming system can affect water quality by: (i) reducing the sediment load due to soil erosion by an increased use of cover crops; (ii) reducing total pesticide load in watercourses since pesticides are prohibited by organic standards; and (iii) affecting the nutrient cycles and nutrient availability to leaching by using green manure and catch crops instead of synthetic fertilizers. It is not clear however whether nutrient losses to surface waters are increased or lowered.

Most of the reviewed models used to simulate the impact of organic farming, with respect to those topics, are meant to assess the nutrient balance and leaching from organic farming systems. Only one dealt with soil erosion at the regional scale, and none dealt with pesticides since they are prohibited by organic standards.

GIBSI already allows for the modelling of crop rotations, which is the core of the organic farming system. It could therefore be easily adapted by including the nutrient contribution of the organic and green manure imported to soils in the GIBSI database. Exported crop yield should also be updated for the organic farming system. The incorporation and mineralization of crop residues to soils is simulated by GIBSI. However, since those processes are particularly relevant to organic farming systems, which mainly depend on the use of green manure and catch crop to replenish the soil nutrient pool, and that they can be very sensitive to the timing of operations, the existing model should be validated for that particular case.

Some parameters and equations that have been used to model the organic farming system, as well as some relevant data from the Organic Field Crop Handbook are included in the appendices for future reference.

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APPENDIX A

Example of organic farms crop rotations from the Organic Field Crop Handbook (Wallace, 2001) and the Fédération d'Agriculture Biologique du Québec (2006)

Farm Name (Owner)	Localisation	Soil Type	Description	Rotation Year	Crop	Detail
[1]Meeting Place Organic farm (Fran and Tony McQuail)	SW Ontario, Northern Huron County	Glacial deposit. Harriston Clay Loam on dolomistic limestone base	100 acres of rolling terrain. Mixed livestock (11 horses, 12 beef, 30 ewe sheep & goat flock), a five ace apple orchard and a two acre CSA garden	1	Winter cereal + clover	Red clover frost seeded into winter grain in spring.
				2	Red clover	One cut of red clover hay followed by grazing; field plowed in late fall.
				3	Mixed cereal + forage	Forage mix planted with a "nurse crop" of mixed grain; compost applied after grain harvest.
				4	Forage	Pasture or hay.
				5	Forage	Pasture or hay.
				6	Forage	Compost spread either before or after the first cut of hay.
				7	Forage Winter cereal	Intensively graze the pasture. Forage plowed; winter cereal planted.
[1]Jervic Farms (Ted and Christine Zettel)	Ontario, Chepstow	Clay loam	190 acres to feed the herd, and 60 acres in cash crop cereals. Livestock: 30 milking Holsteins plus heifers and calves	1	Winter wheat (or spelt) Oilradish	After wheat harvest, oilradish planted and composted liquid manure applied. Oilradish residue covers soil over winter.
				2	Oats + red clover	Oats overseeded with red clover. After oats are harvested, red clover grows more and is chisel plowed in late fall.
				3	Barley Fall rye	After barley is harvested,compost is applied and fall rye planted.
				4	Fall rye Oilradish	Fall rye harvested in mid-summer. Then, oilradish planted and composted liquid manure applied.
				5	Barley + forage	Barley overseeded with alfalfa, timothy and brome.
				6,7,8	Forage	Forage used for hay and pasture.
				9	Forage	Forage crop plowed using mouldboard plow.

[1] from the Organic Field Crop Handbook (Wallace, 2001)

Farm Name (Owner)	Localisation	Soil Type	Description	Rotation		
				Year	Crop	Detail
					Winter wheat (or spelt)	Winter wheat (or spelt) planted.
[1]Oak Manor Farms	Ontario, Tavistock	Clay loam	183 acres workable. Livestock: 60 head beef cattle. Milling operation.	1	Field peas Oilradish	After harvesting peas, oilradish is planted
				2	Spring cereal + clover	Spring cereal planted and overseeded with red clover.
				3	Red clover Winter cereal	Clover chisel-plowed and field cultivated in summer. Winter cereal planted in fall
				4	Winter cereal Buckwheat	Winter cereal harvested in late summer. Buckwheat planted after cereal harvest.
				1,2,3	Alfalfa	Forage crop, plowed in the summer of year 3.
				4	Corn + Ryegrass	Corn overseeded with annual ryegrass: composted manure applied.
				5	Field peas Winter cereal	Field peas planted and harsvested. Winter cereal planted; composted manure applied.
				6	Winter cereal + clover	Clover overseeded into winter cereal.
				7	Vegetables	Composted manure applied before planting vegetables.
				8	Fava beans + forage	Fava beans planted and overseeded with alfalfa or forage grasses.
[1]Tunwath Farm (Basil and Lilian Aldhouse)	Nova Scotia, Annapolis Valley	Loamy sand to sandy clay loam	35 ha field crop	1	Fava beans	Straw and weeds incorporated; fava beans planted.
				2	Oats + clover	Oats oversseded with red clover.
				3	Red clover	Red clover left to grow
				4	Red clover Winter wheat	Clover incorporated and field cultivated. Composted chicken manure applied in late fall.
				5	Winter wheat	Wheat harvested late summer. Straw left in field.
[1]Springwillow Farms (Raymond, Karen, Ricky and Gerrit	Prince Edward Island	Charlottetown sandy loam with an average pH of 5.8 and 4% organic matter.		1	Potatoes	After potato harvest, fall rye is planted
				2	Fall rye Forage	Cattle graze the early growth, then fall rye is incorporated. Forage mix planted.
				3	Forage	Composted manure applied in spring; forage used for hay and grazing

[1] from the Organic Field Crop Handbook (Wallace, 2001)

Farm Name (Owner)	Localisation	Soil Type	Description	Rotation		
				Year	Crop	Detail
Loo)				4	Forage Annual ryegrass	Pasture plowed up; composted manure applied Ryegrass planted immediately after manure is applied
[1] (Ted Zettel)	Ontario		Rotation designed for an Ontario Farm without livestock	1	Winter wheat (or spelt) Oilradish	 Oilradish planted as a fall catch crop after wheat harvest
				2	Oats + peas + clover Clover	Red clover overseeded into oats mixed with peas Clover left to cover the soil over winter
				3	Soybeans Fall rye	Clover incorporated; tillage before planting soybeans Fall rye planted
				4	Fall rye Buckwheat	Fall rye is grown and harvested Buckwheat is frost-killed
				5	Barley + clover	Red cover is overseeded into spring barley
				6	Clover Winter wheat	Red clover harvested for seed
[1](Neil Strayer)	Saskatchewan, Drinkwater	Dark Brown soil	Rotation for a Prairie farm without livestock	1	Wheat	
				2	Flax + sweetclover	Sweetclover is overseeded into the flax
				3	Sweetclover	Sweetclover in incorporated as a green manure
				4	Pulse	Lentil, peas or beans
[1]Hoffman Farm (Larry and Olwen Hoffman)	Saskatchewan, Splading	Black soil	2200 acres	1	Green manure	Red clover or yellow sweetclover
				2	Cereal	
				3	Peas or lentils or flax	
				4	Cereal + green manure	Cereal planted with red clover
[1]Sunrise Organics (Ian and Debbie	Saskatchewan, Rockglen	Brown Soil	1110 acres	1	Spring cereal	Kamut, spring wheat, or durum planted
				2	Lentil	
				3	Flax + green manure	Flax overseeded with yellow sweetclover or intercropped with medic

[1] from the Organic Field Crop Handbook (Wallace, 2001)

Farm Name (Owner)	Localisation	Soil Type	Description	Rotation		
				Year	Crop	Detail
Miller)				4	Green manure	Sweetclover, Indianhead lentils orblack medic
[1]Belvache	Québec, Ste-Anne-Des-Plaines		550 ha Livestock : 90 milking cows	1	Corn	Organic manure applied before corn
				2	Soybeans	
				3	Wheat + green manure	Organic manure applied before wheat
				4	Corn	Organic manure applied before corn
				5	Soybeans	
				6	Wheat	Organic manure applied before wheat
				7	Pasture	
				8	Pasture	
[1]Grain farm model	Québec		Theoretical grain farm model. 170 ha	1	Corn	Organic manure applied in the spring
				2	Soybeans	
				3	Cereal (oat or barley) + green manure	Organic manure applied in the spring
				4	Wheat + red clover	

[1] from the Fédération d'Agriculture Biologique (2006)

APPENDIX B

Equations and parameters from Chambers *et al.* (1999)

Table 2. Default manure analysis values (fresh weight basis).

Manure type	Dry Matter (%)	Total N (kg t^{-1})	Readily available N. NH_4-N plus uric acid N (kg t^{-1})
Cattle FYM – fresh	25	6.0	1.5
Cattle FYM – old	25	6.0	0.6
Pig FYM – fresh	25	7.0	1.8
Pig FYM – old	25	7.0	0.7
Layer manure	30	15	7.5
Broiler/turkey litter	60	29	11.6
Dairy slurry	6	3.0	1.5
Beef slurry	6	2.3	1.2
Pig slurry	4	4.0	2.4
Separated slurry – strainer box	1.5	1.1	1.5
Separated slurry – weeping wall	3	2.0	1.4
Mechanically separated slurry	4	3.0	1.5
Separated slurry solids	15	5.0	1.0
Liquid undigested sewage sludge	5	1.8	0.6
Liquid digested sewage sludge	4	2.0	1.2
Undigested sludge cake	25	7.5	1.5
Digested sludge cake	25	7.5	1.1

MANNER adjusts the manure total N content according to a quadratic equation of the form:

$$N = a + b \cdot DM + c \cdot DM \quad \text{(B.1)}$$

Where N is the total N content (kg·t^{-1} fresh weight), DM is the dry matter content (%), and a, b and c are constants derived for each manure type from a database of analytical results. Similarly, the readily available manure N contents are adjusted in relation to dry matter using the following equation:

$$N_a = d + e \cdot DM \quad \text{(B.2)}$$

where N_a is the readily available N content (as a percentage of total N), DM is the dry matter content (%), and d and e are constants derived from the manure database. For

FYM and sludge cake, total and readily available N contents are assumed to be independent of dry matter content.

Volatilization

Ammonia (NH_3) volatilization is generally the first major loss pathway for manure N following land application. MANNER estimates the quantity of ammonia lost taking into account the time between application and soil incorporation, assuming that losses following thorough incorporation are low. In recent field experiments, ammonia losses were measured over different time periods following the surface application of slurries and solid manures. The measured ammonia losses were fitted with Michaelis-Menten type equation (Figure B.1).

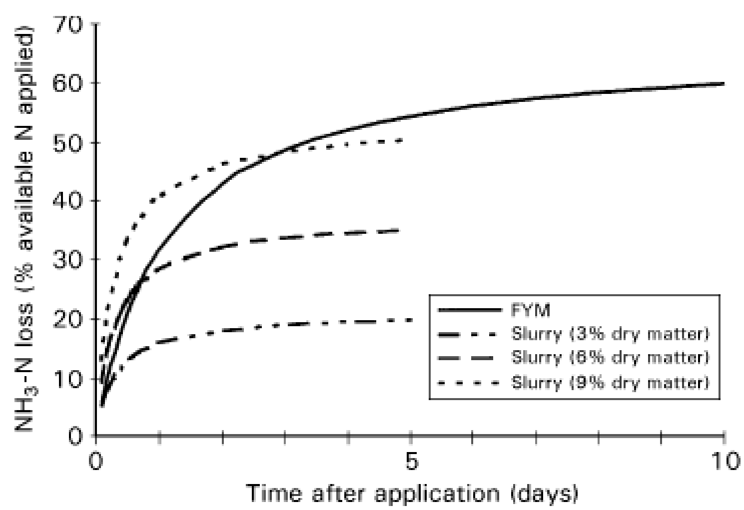

Figure B.1 Selected Michaelis-Menten curves used to predict ammonia losses following land spreading of manures

The equations were of the form:

$$N(t) = N_{\max}(t / t + K_m) \quad \text{(B.3)}$$

where t is the time between manure application and incorporation (days), $N(t)$ is the cumulative NH_3 volatilized after time t (as a percentage of the readily available N applied), N_{max} is the maximum NH_3 loss as t approaches infinity, and K_m is the time when $N(t) = 0.5\ N_{max}$. Using these equations, N_{max} and K_m values were derived for the different solid manure types, to estimate ammonia losses between the time of application and incorporation. In the absence of experimental data on ammonia losses following the land application of sewage sludge cakes, ammonia losses were assumed to follow the same pattern as *FYM*. MANNER adjusts the potential ammonia volatilization (N_{max}) in relation to the slurry dry matter content, before estimating ammonia emissions using an appropriate Michaelis-Menten equation (Figure B.1). Ammonia losses from separated slurries and liquid sludges were calculated in the same way.

Crop uptake

No allowance is made in the model for crop uptake of N following autumn manure applications, because this is usually small, with crop N requirements fully supported by soil N supply before the addition of manures.

Nitrate leaching

Following manure applications to land, NH_4-N (plus uric acid N for poultry manures) will be converted to nitrate N (NO_3-N) which is susceptible to loss through overwinter leaching. MANNER calculates the amount of nitrogen lost through nitrate leaching based on the amount of readily available N remaining in the soil after losses via ammonia volatilization have been accounted for. The total water content of the soil profile at field capacity (volumetric moisture content) is defined by the soil type and/or texture and determines the soil's susceptibility to leaching. In the model, the soil type and/or texture can be defined for the topsoil (0-30 cm) and the subsoil (30-90 cm). Fifteen different soil types/textures are recognised which are detailed, along with the topsoil and subsoil volumetric moisture (V_m) contents. A simple piston flow model is used to describe water movement through the soil profile. This assumes that the volume of water entering the soil as rainfall displaces an equal volume of water from the soil through drainage. However, not all the rainfall will drain into the soil as some will be lost through evapotranspiration. The "effective" rainfall (ER) is thus the difference between actual rainfall (AR) and the amount lost through evapotranspiration. Data on evapotranspiration losses from fields with different crop cover types can be obtained from the Meteorological Office, however, it is unlikely that most farmers will have ready access to this. The model therefore uses a simple algorithm to calculate ER from AR. This is based on results of actual and effective rainfall measurements made between 1989 and 1993 at 24 sites where cereal crops were grown.

$$ER = (0.86 \cdot AR) - 60.9 \quad \text{(B.4)}$$

The model requires an entry for the rainfall following the date of manure application until the date when drainage ends. If the end of drainage date is not known, MANNER assumes a typical date of 31 March. If rainfall data is lacking, the model applies a typical annual rainfall value for central lowland England (720 mm) with adjustment for evapotranspiration appropriate for each month to give an annual ER of 275mm. ER is then adjusted depending on the time between manure application and the end of drainage date. N leaching losses from the soil profile are calculated based on the amount of readily available N remaining after ammonia volatilization, using the following relationship:

$$AN_1 = AN_v \cdot (ER / V_{m_s} - 0.4) \tag{B.5}$$

Where AN_1 is the amount of readily available N remaining after leaching, AN_v is the amount of readily available N remaining after ammonia volatilization, and V_{ms} is the volumetric moisture content of the topsoil plus that of the subsoil. If the manure was ploughed down within 1 month of application, it is assumed to have "by-passed" half the topsoil (average incorporation depth c. 30 cm) and V_{ms} therefore accounts for only half the volumetric moisture capacity of the topsoil plus that of the subsoil, before being used in Eq. (B.5).

Mineralization

Mineralization of manure organic N over an extended period will result in some N becoming available for crop uptake, even if all the applied readily available N has previously been lost through ammonia volatilization or nitrate leaching. For MANNER, data from field experiments conducted in the UK were used to derive the following simple mineralization equations, which apply to both surface applied and incorporated manures:

$$N_m = N_o \cdot 0.1 \; N_m = N_o \cdot 0.1 \tag{B.6}$$

for *FYM*, slurries and spring applied poultry manure;

$$N_m = N_o \cdot 0.2 \tag{B.7}$$

for autumn applied poultry manure.

Where N_o is the amount of organic N in the manure and N_m is the amount of organic N mineralized. Mineralization rates for sewage sludge products were assumed to be the same as in Eq. (B.6).

APPENDIX C

Equation of the ROTOR model from Bachinger and Zander (2007)

Some restrictions regarding crop rotations are defined to avoid unfavourable crop sequences and ineffective use of the limited nitrogen sources from legumes or manure: (i) no leaf crop after leaf crop; (ii) no wheat after cereal; (iii) no grain legumes after grain legumes or legume grass; (iv) no manure application to legumes or legumes-grass; (v) no preceding CPAs (crop production activities) with low N residues for crop with high nitrogen demand (potato, wheat, winter rape, and silage corn). Also, residual N (classified with only three discrete classes: low, medium, high) of the preceding CPA must fulfill the need of the following CPA. The best rotations are selected according to exclusion criteria regarding the mean results of the assessment module for the CPAs of each rotation (*i.e.* thresholds for N balance, weed infestation risks, phytosanitary and chronological restrictions) and ranked according to chosen criteria (*e.g.* economic performance). Figure C.1 illustrates ROTOR’s structure.

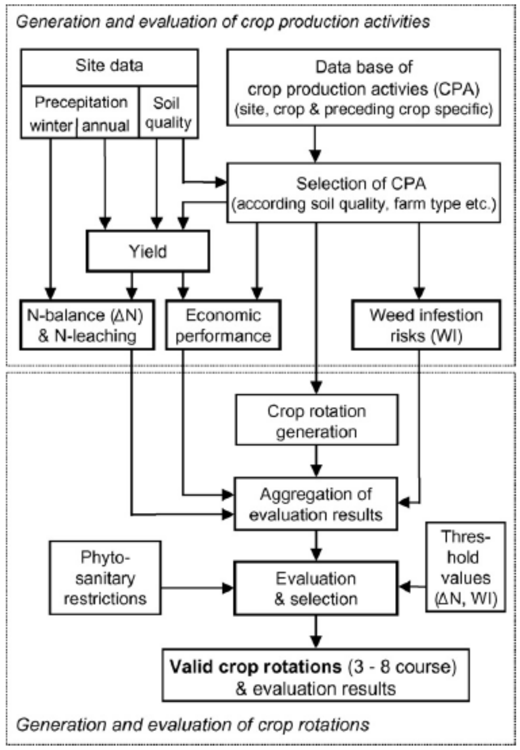

Figure C.1 **Model structure of ROTOR, consisting of the CPA generation and evaluation (top) and crop rotation generation and selection and specified evaluation results (bottom) according to the agronomic restrictions (threshold values for N-balance, weed infestation risks and phytosanitary restrictions). Evaluation modules are marked with bold frames (from Bachinger and Zander, 2007)**

The annual N balance of each CPA is calculated with the following equation:

$$\Delta N_{\mathrm{CPA}} = (N_{\mathrm{fix}} + N_{\mathrm{m}} + N_{\mathrm{s}}) - (N_{\mathrm{remov}} + N_{\mathrm{lea}} + N_{\mathrm{vol}}) \tag{C.1}$$

Where:

ΔN_{CPA}: CPA-specific N balance (kg N·ha^{-1});

N_{fix}: N_2- fixation of grain legumes calculated with Eq. (C.2) and of fodder legumes grass mixtures calculated with Eq. (C.3) (kg N·ha^{-1});

N_{m}: N in manure (kg N·ha^{-1});

N_{s}: N in seeds (kg N·ha^{-1});

N_{remov}: N removal of harvested products (kg N·ha^{-1});

N_{lea}: NO_3- leaching calculated with Eq. (C.4) (kg N·ha^{-1});

N_{vol}: NH_3- volatilization out of mulched biomass from set-aside (estimated at 10% of total N) (kg N·ha^{-1}).

The N_2-fixation of grain legumes is calculated crop, preceding crop and yield specific with the following equation:

$$N_{fix} = Y_{CPA} \cdot N_C \cdot R_{NR} \cdot R_{Nfix} \cdot R_{Nfix\text{-}red} \quad \text{(C.2)}$$

Where :

Y_{CPA} : CPA specific yield estimated from yield functions for conventional farming systems, yield data and expert assessments for different soil;

N_C : N content of the harvested grain dry matter (%);

R_{NR} : Crop specific ratio of N in grain yield to N in crop and root residues;

R_{Nfix} : Ratio of symbiotically fixed N to total N (set to 0.75);

$R_{Nfix\text{-}red}$: Parameter used to reduce the R_{Nfix} for CPAs with medium residual N to take into account the effect of decreased N_2-fixation caused by increased soil contents of mineralised N from preceding crop residues in spring (set to 0.8).

The N_2-fixation of legumes-grass mixtures can be computed from different percentages of legumes in the dry matter of the gross yield with the following equation:

$$N_{fix} = (Y_{tot} \cdot R_L \cdot N_L \cdot R_{Nres} \cdot R_{LNfix\text{-}red} + Y_{tot}(1\text{-}R_L) \cdot N_G \cdot R_{GNfix}) \quad \text{(C.3)}$$

Where:

Y_{tot} : Total dry matter yield without harvest losses at 5 cm cutting height (t·ha^{-1}) (calculated as $Y_{tot} = Y_{CPA} \cdot R^{-1}_{Hloss}$, where Y_{CPA} is the CPA specific yield - estimated from yield functions for conventional farming systems, yield data and expert assessments for different soil - and R_{Hloss} is the ratio of harvest losses set to 0.65 for hay and 0.85 for silage crop);

R_L: Legume portion in the dry matter yield;

N_L : N content in legume dry matter (%);

R_{Nres}: Ratio of N in legume yield to N in stubble and root residues;

$R_{LNfix\text{-}red}$: Ratio of symbiotically fixed N to total N in legumes (calculated for forage use as $R_{LNfix\text{-}red} = 0.17R_L + 0.98$ and for set aside as $R_{LNfix} = -0.4R_L + 0.95$);

N_G : N content in grass yield;

R_{GNfix} : Ratio of fixed N transferred to grass ($R_{GNfix} = 0.25R_L$).

The NO_3-leaching (N_{lea}) of CPAs is calculated as a function of the soil leaching probability and N surplus with the following equation:

$$N_{lea} = N_{surp} \cdot L_P + N_{upt\text{-}CC} \cdot R_{EP\text{-}CC} \cdot R_{remin\text{-}CC} \cdot L_P \cdot R_{LF\text{-}CC} \qquad (C.4)$$

Where:

N_{surp}: N surplus ($kg \cdot ha^{-1}$), calculated with Eq. (C.5);

L_P: Leaching probability during the winter half year (L_P is mean winter precipitation/water holding capacity at rooting depth; L_P values > 1 are set to 1);

$N_{upt\text{-}CC}$: N uptake of catch crops ($kg\ N \cdot ha^{-1}$);

$R_{EP\text{-}CC}$: Dimensionless coefficient describing the establishment probability of a crop density with efficient N uptake of different catch crops (set to 0.4 for stubble seeds, to 0.8 for grass undersown in spring crops and to 0.7 for legume grass undersown in winter crops);

$R_{\text{remin-CC}}$: Coefficient describing N remineralising probability from catch crop residues after winter kill (for *sinapis alba* set to 0.75) (kg N·ha^{-1});

$R_{\text{LF-CC}}$: Reduction coefficient of leaching probability after the remineralization of catch crop residues (set to 0.5).

The equation for N surplus is:

$$N_{\text{surp}} = N_{\text{min}} - N_{\text{remov}} - N_{\text{upt-CC}} \cdot R_{\text{EP-CC}} \quad \text{(C.5)}$$

Where:

N_{min}: CPA specific N mineralization (kg·N ha^{-1}), calculated with Eq. (C.6)

The site and CPA-specific mean nitrogen mineralization calculated with Eq. (C.6) was assumed to be a function of the total organic nitrogen content (N_{org}) modified by the N supply level, specific for the preceding crop type. The site-specific organic carbon content of soils from glacial deposits in North Eastern Germany is assumed stable in agronomically suitable organic crop rotations with a well-balanced N supply:

$$N_{\text{min}} = N_{\text{org}} \cdot R_{\text{mina}} \cdot R_{\text{minNL}} \cdot R_{\text{minC}} \quad \text{(C.6)}$$

Where:

N_{org} : Organic N content (kg N·ha^{-1}) in plough horizon (Ap) calculated with Eq. (C.7);

R_{mina} : Mean annual soil N mineralization rate of N_{org} (assumed as 0.02);

R_{minNL}: Coefficient of the preceding crop specific residual N level calculated with Eq. (C.10);

R_{minC}: Crop specific coefficient to modify N_{min} depending on tillage intensity (*e.g.*, 1 for cereals, 1.4 for potato);

$$N_{org} = R_{Corg} \cdot R^{-1}_{CN} \cdot BD \cdot D_{Ap} \cdot 10^5 \quad (C.7)$$

$$R_{Corg} = R_{FE} \cdot 0.023 + 0.4 \quad (C.8)$$

$$R_{FE} = 0.0077 \cdot SRI^2 + 0.055 \cdot SRI \quad (C.9)$$

Where :

R_{Corg}: Content of organic carbon in topsoil (%), calculated with Eq. (C.8);

R_{CN}: C/N ratio (assumed as 11);

BD: Bulk density estimated as 1.55 (g·cm^{-3});

D_{Ap}: Depth of plough horizon (cm);

R_{FE} : Fine earth (particle size < 6.3 μm) content of Ap (%) calculated with Eq. (C.9);

SRI : Soil rating index.

In the static approach of ROTOR, no distinction was possible either between the amounts of N mineralization out of different pools of soil organic matter or between organic and inorganic N residues. The different N pools were indirectly taken into account in Eq. (C.6) by including a coefficient, calculated with Eq. (C.10), for the different preceding crop specific residual N levels (*NL*). The residual N level results from the short-term N dynamics caused by rapidly mineralisable organic and inorganic N residues from the preceding crop:

$$R_{minNL}\{NL\} = \begin{cases} 1; & NL: \text{low} \\ 1 + (-0.0056 \cdot SRI + 0.513); & NL: \text{medium} \\ 1 + (-0.0114 \cdot SRI + 1.034); & NL: \text{high} \end{cases}$$

(C.10)

Parameter values of Eq. (C.10) used to calculate the annual N mineralization were calibrated using the calculated N removal of winter rye and results of soil N dynamic simulations using a dynamic model that simulates water and soil nitrogen dynamics.

APPENDIX D

Crop yield values, N balance and modelled N leaching for organic and conventional farms in Denmark from Hansen *et al*. (2000)

Table 1
Crop yields and nitrogen fixation for conventional farming systems from the Agricultural Catchment Monitoring

Loamy soils			Sandy soils		
Crop rotation	Yields[a] FU ha^{-1}	N-fixation[b] kg N ha^{-1} $year^{-1}$	Crop rotation	Yields[a] FU ha^{-1}	N-fixation[b] kg N ha^{-1} $year^{-1}$
Conv. Arable					
Winter wheat	8400	2	Winter wheat	5900	2
Spring barley	6000	2	Spring barley	3900	2
Root crops	11600	2	Root crops	–	2
Legumes	6000	188	Legumes	5300	168
Oil-seed rape	4500	2	Oil-seed rape	–	–
Grass	–		Grass	–	–
Conv. pig framing					
Winter wheat	8100	2	Winter wheat	6800	2
Spring barley	5800	2	Spring barley	5000	2
Root crops	12200	2	Root crops	–	–
Legumes	–	–	Legumes	4200	131
Oil-seed rape	3800	2	Oil-seed rape	4400	2
Grass	–	–	Grass	–	–
Conv. dairy/beef farming					
Winter wheat	7850	2	Winter wheat	7200	2
Spring barley	5200	2	Spring barley	4500	2
Root crops	12000	2	Root crops	10000	1
Legumes	5200	164	Legumes	3600	112
Oil-seed rape	2600	1	Oil-seed rape	1800	2
Grass	6700	38	Grass	6400	37

[a] Crop yield in main crop+catch crop. All yields are shown in Scandinavian feed units (FU). One FU corresponds to 1 kg of barley.
[b] N-fixation is calculated according to Kyllingsbæk (1995).

Table 2

Crop yields and nitrogen fixation in organic arable crop, and in pig and dairy/beef production systems based on Simmelsgaard et al. (1998)[a]

Loamy soils				Sandy soils			
Crop rotation	Yields[a] FU ha^{-1}	Clover- yields[b] hkg ha^{-1}	N_2-fixation kg N ha^{-1} $year^{-1}$	Crop rotation	Yields[a] FU ha^{-1}	Clover-yields[b] hkg ha^{-1}	N_2-fixation kg N ha^{-1} $year^{-1}$
Organic arable crop farm				*Organic arable crop farm*			
Spring barley with undersown grass-clover	3770	8	36	Spring barley with undersown grass-clover	2720	7	31
Grass-clover (50%)	0	36	166	Grass-clover (50%)	0	30	139
Winter wheat with catch crop	5020	4	22	Oats with catch crop	3930	3	19
Spring barley with catch crop	4460	4	22	Winter rye with catch crop	2740	3	19
Oats	3650			Spring barley	3060		
Organic pig farm				*Organic pig farm (irrigated soil)*			
Spring cereal with undersown grass-clover	4028	7	43	Spring cereal with undersown grass-clover	2849	6	37
Grass-clover (38%)	3518	30	186	Grass-clover (38%)	3315	28	174
Spring cereal with catch crop	4735	3	19	Spring cereal with catch crop	3667	2	12
Spring barley with catch crop	4017	3	19	Spring barley with catch crop	2849	2	12
Spring cereal	3982	0	0	Spring cereal	2849	0	0
Organic dairy/beef farm				*Organic dairy/beef farm (irrigated soil)*			
Barley/pea with undersown grass-clover (15% pea)	3900+390	6	54	Barley/pea with undersown grass-clover (30% pea)	3500+390	5	68
Grass-clover (26%)	6100	25	143	Grass-clover (26%)	5900	24	137
Grass-clover (26%)	6100	25	143	Grass-clover (26%)	5900	24	137
Spring cereal with catch crop	3300+390			Spring cereal with catch crop	3300+390		
Spring cereal with catch crop	3300+390			Spring cereal with catch crop	3300+390		

[a] Crop yields are based on registrations from organic farms in Denmark from 1987 to 1996. Crop yield in main crop+catch crop. All yields are shown in Scandinavian feed units (FU). One FU corresponds to 1 kg of barley.

[b] Dry matter-production in clover-grass is assumed to be 7.1 t ha^{-1} (6100 FU/ha with 1.16 kg dry matter per FU) on loamy soil, 6.0 t ha^{-1} (5200 FU ha^{-1} with 1.16 kg dry matter per FU) on non-irrigated sandy soil, and 6.8 t ha^{-1} (5900 FU ha^{-1} with 1.16 kg dry matter per FU) on irrigated sandy soil. Yields are from Halberg and Kristensen (1997) and the nitrogen concentration from Strudsholm et al. (1995).

Table 4

N-balances and modelled N-leaching for conventional (conv.) and organic (org.) agricultural production systems (kg N ha^{-1} $year^{-1}$)[a]

			LU ha^{-1}[a]	Total N	$N_{atmosphere}$[b]	N_{manure}	$N_{fertiliser}$	N_{yield}	N_{net}	$N_{leaching}$[c]
Arable crop farm	Loam	Conv.		146	22	4	120	121	25	32
		Org.		116	69	47	0	56	60	19 (29)
	Sand	Conv.		212	31	96	85	105	107	90
		Org.		104	61	43	0	44	60	36 (46)
Pig farm	Loam	Conv.	1.4	212	25	102	86	115	97	46
		Org.	0.8 (1.2)	214	73	141	0	87	126	30 (49)
	Sand	Conv.	1.5	227	31	126	70	106	122	111
		Org.	0.6 (1.3)	211	67	144	0	68	143	61 (95)
Dairy/beef farm	Loam	Conv.	1.4	241	25	130	87	150	91	48
		Org.	1.0	215	90	126	0	120	95	28 (49)
	Sand	Conv.	1.8	311	41	160	111	156	155	103
		Org.	1.0	216	91	124	0	117	99	65 (104)

[a] Values in parentheses include imported animal manure.

[b] N_2-fixation plus atmospheric deposition (the latter set at 20 kg N ha^{-1} $year^{-1}$).

[c] values in parentheses are modelled nitrogen leaching for organic agricultural systems without catch crops.

APPENDIX E

Illustration of the soil organic matter submodel and functions for the adjustment of parameters of DAISY from Hansen *et al*. (1991)

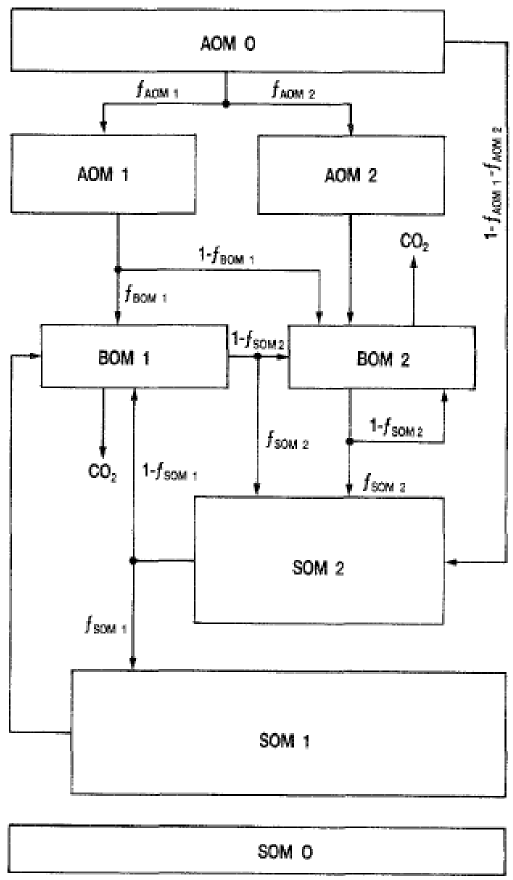

Figure E.1 **The DAISY submodel of soil organic matter. Pools and subpools (1 and 2) of organic matter and related partitioning coefficients (f). AOM: added organic matter, BOM: microbial biomass, SOM: native soil organic matter**

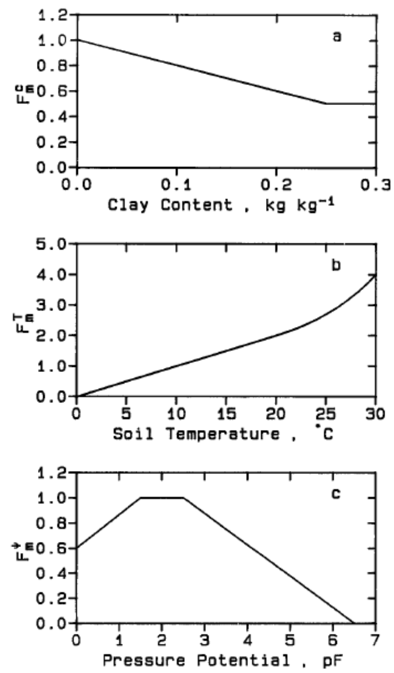

Figure E.2 Abiotic functions for adjustment of decomposition rate coefficients to clay content (a), soil temperature (b), and soil water pressure potential (c)

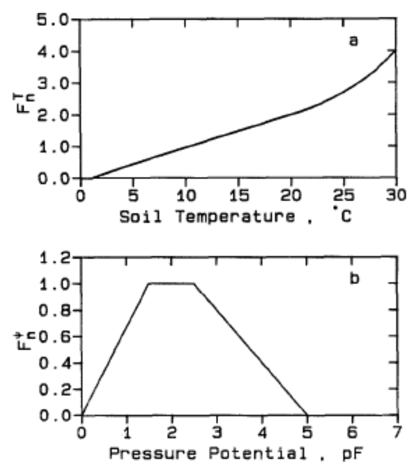

Figure E.3 Abiotic functions for adjustment of nitrification rate coefficients to soil temperature (a), and soil water pressure potential (b)

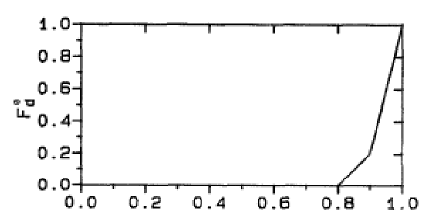

Figure E.4 Soil water content function for adjustment of denitrification rate to the degree of water saturation

APPENDIX F

Parameters and results from Knudsen *et al*. (2006)

Table 1. *Representative characteristics and area-based averages of mixed dairy and arable farms in 1999, Denmark*

	Mixed dairy farms									
	Organic			Conventional					Arable farms	
				Sandy		Sandy loam			Organic	Conventional
LSU*/ha:	Sandy	Sandy loam	Average	<1·4	1·4–2·3	<1·4	1·4–2·3	Average	Average	Average
Representativity										
Number of farms in dataset	125	24	149	83	182	23	32	350	137	105
Represented agricultural area (1000 ha)	71	10	81	156	261	43	43	530	51	294
Herd										
Cows per farm (cows/farm)	85	62	82	48	67	55	55	61	0	0
LSU* per farm (LSU/farm)	133	100	128	81	109	87	84	99	13	2
Stocking rate (LSU/ha)	1·3	1·1	1·3	1·0	1·7	0·9	1·7	1·5	0·3	0·0
Area										
Farm area (ha/farm)	102	88	100	81	65	99	50	68	37	72
Crop rotation (fraction of farm area):										
Permanent grass	0·09	0·11	0·09	0·09	0·11	0·09	0·08	0·09	0·08	0·01
Set-aside	0·05	0·05	0·05	0·07	0·06	0·06	0·04	0·06	0·07	0·09
Cereal for harvest	0·14	0·23	0·15	0·40	0·19	0·46	0·32	0·29	0·51	0·68
Maize/whole crop silage	0·29	0·23	0·29	0·16	0·33	0·13	0·21	0·27	0·09	0·00
Grass/clover in rotation	0·41	0·33	0·40	0·18	0·26	0·14	0·25	0·22	0·12	0·01
Other crops	0·02	0·05	0·02	0·10	0·05	0·12	0·10	0·07	0·13	0·21
Production										
Cereal yield (t/ha)	4·1	4·4	4·2	5·2	4·9	5·6	5·4	5·2	3·4	5·9
Milk yield (kg milk/cow/year)	6861	6811	6855	7431	7429	7227	7288	7373	0	0

* Livestock units (LSU), DK definition: 0·85 LSU = 1 dairy cow on 7500 l milk/year.

Table 2. *Organic arable crop rotation 1999 for the FASSET simulation model. Furthermore possible catch crops and incorporation of straw are noted*

Organic crop rotation	Conventional pig slurry kg N/ha	Organic manure kg N/ha	Incorporation of straw	Catch crops	Type of catch crop
1. Spring barley		83	+/−	+/−	Ryegrass
2. Field peas			+	−	
3. Rye	85		+/−	+/−	Ryegrass
4. Spring wheat + catch crop		83	+/−	+	Grass/clover
5. Spring barley	85		+/−	+/−	Grass/clover
6. Spring barley + catch crop		83	−	+	
7. Grass/clover, silage				−	
8. Grass/clover, set-aside				−	
9. Spring wheat + catch crop	56		+/−	+	Ryegrass
10. Spring barley/field peas, silage + catch crop	43		−	+	Grass/clover
Average	27	25			

Table 3. *Conventional arable crop rotation 1999 for the FASSET simulation model. Further possible catch crops and incorporation of straw are noted*

Conventional crop rotation	Conventional pig slurry kg N/ha	Mineral fertilizer kg N/ha	Incorporation of straw	Catch crops	Type of catch crop
1. Spring barley	115	38	+/−	−	
2. Winter barley		151	+/−	−	
3. Winter oilseed rape	80	109	+	−	
4. Winter wheat		134	+/−	−	
5. Winter wheat		169	+/−	+/−	Ryegrass
6. Spring barley + catch crop	115	38	+/−	+	Ryegrass
7. Spring barley	115	38	+/−	+/−	Ryegrass
8. Spring barley		124	+/−	−	
9. Winter wheat		134	+/−	−	
10. Rye		111	+/−	+/−	Ryegrass
Average	39	95			

Table 8. *N balances for the basis arable farm scenarios at different soil types using the FASSET simulation model (kg N/ha/year)*

	Organic						Conventional					
	Sandy		Loamy sand		Sandy loam		Sandy		Loamy sand		Sandy loam	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Input												
Mineral	0	0	0	0	0	0	95	95	95	95	95	95
Organic	52	52	52	52	52	52	39	39	39	39	39	39
Fixation	75	81	74	81	78	84	0	0	0	0	0	0
Other*	16	16	16	16	16	16	16	16	16	16	16	16
Total input	143	149	143	149	146	153	150	150	150	150	150	150
Output												
Grains	−44	−40	−46	−41	−49	−44	−84	−77	−85	−78	−93	−83
Straw + silage	−42	−38	−44	−40	−46	−42	−28	−24	−30	−25	−27	−22
Total output	−87	−78	−91	−81	−96	−86	−112	−101	−115	−103	−120	−106
Field N balance	56	71	52	68	50	67	38	49	34	46	29	44
N loss												
Leaching	−56	−42	−44	−33	−24	−16	−56	−41	−46	−32	−23	−15
Ammonia	−3	−3	−3	−3	−3	−3	−2	−2	−2	−2	−2	−2
$N_2 + N_2O$	−3	−3	−8	−7	−24	−19	−3	−3	−7	−6	−23	−18
Total N loss	−62	−48	−55	−42	−51	−38	−62	−45	−56	−41	−48	−35
Storage												
Soil	−4	24	0	26	3	30	−21	4	−18	7	−16	9
Mineral N	−2	−1	−3	−1	−3	−1	−3	−1	−3	−1	−4	−1

* N deposition and seed N.

Table 9. *N leaching loss (kg N/ha/year) for all arable farm scenarios at the different soil types and soil fertility levels using the FASSET simulation model*

	Sandy		Loamy sand		Sandy loam		
	High	Low	High	Low	High	Low	Average
Organic							
Basic	56	42	44	33	24	16	36
+ catch crop	46	33	35	24	16	10	27
+ incorporation of straw	53	39	42	30	22	15	33
+ straw and catch crop	44	31	34	23	15	9	26
0·5 fertilization	52	39	41	30	23	16	34
0 fertilization	49	37	39	29	22	15	32
0·10 grass/clover	52	38	41	30	23	15	33
Conventional							
Basic	56	41	46	32	23	15	36
+ catch crop	49	33	40	26	18	10	29
+ incorporation of straw	56	40	46	32	21	14	35

APPENDIX G

Description of FARMFLOW, parameters, and results from Modin-Edman *et al*. (2007)

In FARMFLOW, the P content is modelled in two soil layers. In each soil layer are three soil P pools; slow P (sparingly soluble), fast P (plant available sorbed) and P in soil solution (Figure G.1). To mimic the low soil solution P concentrations generally found in Swedish agricultural soils, the soil solution does not contain more P than is immediately used by the crops. A mass-balance is made for each soil P pool in topsoil and subsoil layers. Phosphorus from solid manure, seed and atmospheric deposition is added to the topsoil fast P pool. Phosphorus in these inputs is regarded as being adsorbed to solids and needs to be desorbed to become available for the crops. However, P in liquid manure and mineral fertilisers is added to the topsoil solution and is assumed to be immediately available. The crop uptake takes place from the soil solution of the topsoil layer and, if requirements are not met, from the subsoil layer soil solution. Phosphorus uptake by the crops takes place during the growth season, the length of which must be made crop and site specific by the user. The harvested amount of P in each crop is input to the model and is used as a target value for plant uptake. Recirculation of organically bound P in crop residues is not described dynamically.

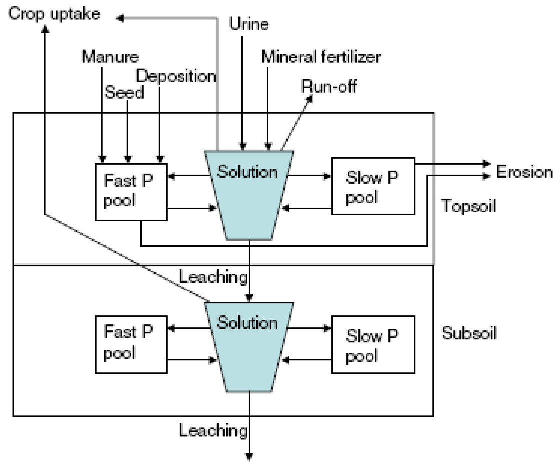

Figure G.1 FARMFLOW soil P content described as one slow pool (P-HCl), one fast pool (P-Al) and P in soil solution (from Modin-Edman *et al*., 2007)

The P dynamics are described in a simplistic manner with first order reaction kinetics. The coefficients are calibrated and were determined by iterative parameterisation adjusting to very low soil solution P concentrations, corresponding to observed levels in combination with results from the Swedish long-term fertilisation experiments where changes in soil P–Al values can be related to soil P balances. Results from the fertilisation experimental sites situated in the same region and having similar crop rotations were used. In each soil layer, P in the fast and slow P pools is released into soil solution at rates (g P·ha^{-1}·yr^{-1}) that is depending on pool size (g P·ha^{-1}) and release coefficients k_r (yr^{-1}) (Eq. (G.1) and Table G.1). In addition, a dimensionless layer specific soil moisture coefficient, k_m, is included in the equations. At drought or when the soil is waterlogged, the reactions will be hampered. Implicitly, the soil aeration is hence included. Other factors that may influence the P transformations in soils, such as temperature and pH, are not included in FARMFLOW.

$$P_{outsoilPpool}[Field] = SoilPpool[Field]\ k_{r,soilPpool} \cdot k_{m,soillayer} \quad (G.1)$$

The transfer of P from soil solution to the P pools of each soil layer is dependent on soil solution concentration of P, [P] (g P·m^{-3}·ha^{-1}), and pool specific coefficients, k_b (m^3·yr^{-1}) (Eq. (G.1) and Table G.1). The linear relationships implies that there is no adsorption maximum simulated for the fast P pools in the soil, i.e. it is assumed that the soils simulated are far from saturation with respect to adsorbed P.

$$P_{insoilPpool}[Field] = [P]_{soillayer}[Field]\ k_{b,soilPpool} \qquad (G.2)$$

Table G.1 Coefficients for P transfer (binding k_b and release k_r) between soil solution and the fast (P-Al) and solw (P-HCl) soil pools in topsoil (0-25 cm) and subsoil (25-85 cm)

	Topsoil		Subsoil	
	Fast P pool	**Slow P pool**	**Fast P pool**	**Slow P pool**
k_b	50 000	500 000	5 000	5 000 000
k_r	0.5	0.00001	0.1	0.00001

FARMFLOW calculates losses of soluble P from the soil system as the combination of water flow in percolation and runoff, and P content in soil solution. A substantial proportion of the P losses from Swedish agricultural soils are in the form of particulate P, *i.e.* soil particles with adsorbed and/or precipitated P, which are transported by runoff and/or percolation. In FARMFLOW this process is included by erosion of the fast and slow P pools of the topsoil, which takes place at simulated high surface water flow events. Internal erosion and transport of P in macropores in the soil is not described. P losses directly associated with the surface application of manure are not simulated in FARMFLOW.

Table 2
The FARMFLOW model parameters for organic and conventional management practices at the Öjebyn experimental farm (Bengtsson et al., 2003; Gustafson et al., 2003; Jonsson, 2004)

Parameter	Unit	Organic	Conventional
Average transit time for cows in the system	Years	3	3
Number of cows the barn can house	#	50	50
Amount of silage fed per cow	kg dw cow^{-1}	5647	4059
Amount of feed (barley) fed per cow	kg dw cow^{-1}	4326	6410
Average live weight of imported animals	kg $animal^{-1}$	540	520
Average live weight of exported cows	kg $animal^{-1}$	650	670
Import and use of P in minerals, concentrates, additives	kg P cow^{-1} yr^{-1}	7.1	9.5
Import and use of P in bedding material for the stable	kg P yr^{-1}	1.0	1.0
Milk production, average	kg cow^{-1} yr^{-1}	8600	9334
Amount of urine excreted	kg dw cow^{-1} yr^{-1}	662	626
Number of fields in the crop rotation	#	6	6
Size of each field	ha	Table 3	Table 3
Soil P content (P–Al) in topsoil and subsoil	Mg P ha^{-1}	Table 3	Table 3
Soil P content (P–HCl) in topsoil and subsoil	Mg P ha^{-1}	Table 3	Table 3
Mineral fertiliser fertilisation strategy (crop specific)	kg P ha^{-1} yr^{-1}	0	13.0 (to potato)
Manure fertilisation strategy (crop specific)	Proportion of manure pad	See text, Section 3.1	See text, Section 3.1
Urine fertilisation strategy (crop specific)	Proportion of urine tank	See text, Section 3.1	See text, Section 3.1
P addition in seed (crop specific)	g P ha^{-1} yr^{-1}	Table 4	Table 4
Average harvest of P (crop specific)	kg P ha^{-1} yr^{-1}	Table 5	Table 5
Atmospheric P deposition	g P ha^{-1} yr^{-1}	400	400
Precipitation	mm yr^{1}	500	500

Table 3
Field size (ha) and initial P content (Mg P ha^{-1}) in the soil pools of the organic and conventional farming systems at Öjebyn

Field #	Field size (ha)		Slow pool (topsoil + subsoil) (Mg P ha^{-1})		Fast pool (topsoil + subsoil) (Mg P ha^{-1})	
	Organic	Conventional	Organic	Conventional	Organic	Conventional
1	8.87	5.82	2.5 + 5.9	2.6 + 7.1	0.3 + 0.5	0.2 + 0.7
2	7.52	6.22	2.6 + 5.7	2.4 + 6.1	0.2 + 0.4	0.2 + 0.3
3	8.88	7.75	4.3 + 7.0	1.9 + 6.9	0.4 + 0.7	0.3 + 0.3
4	8.56	6.30	3.6 + 6.4	2.5 + 5.1	0.1 + 0.4	0.3 + 0.3
5	8.18	7.35	2.6 + 7.5	2.8 + 5.7	0.2 + 0.3	0.3 + 0.3
6	7.91	5.38	2.7 + 8.5	2.1 + 4.9	0.2 + 0.2	0.3 + 0.4

Table 4
The crop specific addition of P per hectare in seed in the organic and conventional management systems at Öjebyn

Crop	Organic (g P ha^{-1})	Conventional (g P ha^{-1})
Oats and Peas	920	846
Ley1	84	85
Ley2	0	0
Ley3	0	0
Barley	629	558
Potato	575	575

Table 5
The average crop specific harvest of P (kg P ha^{-1}) in the organic and conventional management systems at Öjebyn during the period 1990–2001

Crop	Organic (kg P ha^{-1})	Conventional (kg P ha^{-1})
Oats and peas	14.3	10.4
Ley1	21.6	22.4
Ley2	20.4	19.6
Ley3	15.8	16.4
Barley	13.6	13.3
Potato	9.2	9.3

APPENDIX H

Nutrient value of some permitted fertility and soil amendments from the Organic Field Crop Handbook (Wallace, 2001)

Some permitted fertility and soil amendments

Organic amendment	Primary benefit	Average analysis (N–P–K)	Comments
Alfalfa meal	Nitrogen	5–1–2	Contains triaconatol, a natural fatty acid growth stimulant, plus trace minerals.
Basalt	Calcium, Magnesium		Weathers easily, releasing nutrients and micronutrients.
Blood meal R	Nitrogen	12–0–0	Must be composted and obtained from organically raised livestock.
Bonemeal R	Phosphate	1–11–0 to 6–12–0	Must be composted and obtained from organically raised livestock.
Borax (hydrated sodium borate)	Micronutrients	10% boron	Toxic in excess. Test soils before application.
Chelates R & sulphates	Micronutrients, lower pH		Use only when tissue or soil tests show deficiencies, and check to see if deficiencies are due to soil imbalances. Used as foliar applications to provide Mn, Fe, Cu and Zn. Sulfates are used to lower soil pH.
Crab meal R	Nitrogen	4–3–0.5	Like fish meal, must be composted. Also used to control harmful nematodes.
Epsom salts (magnesium sulfate).	Magnesium	10–20% magnesium	Test soils before application. Can be foliar fed to correct deficiencies.
Fish emulsions R	Nitrogen Phosphorous	4–4–1; 5% sulfur	Usually diluted 20:1, and one gallon will treat one acre.
Fish meal R	Nitrogen, Phosphorous	5–3–3	Must be composted.
Granite meal	Potassium Micronutrients	4% total potash, 67% silica & 19 micronutrients	Provides low levels of potassium and micronutrients.
Greensand (glauconite)	Potassium	7% total potash plus 32 micronutrients	Improves soil structure and water-holding capacity. Absorbs 3 times its weight in water.
Gypsum (calcium sulfate)	Calcium	22% calcium; 17% sulfur	Do not apply if the soil pH is below 5.8. Small amounts loosen clay soil. Moderate amounts increase calcium and lower potassium or magnesium levels.

Some permitted fertility and soil amendments

Organic amendment	Primary benefit	Average analysis (N–P–K)	Comments
Kelp (seaweed) meal	Potassium, micronutrients	1.5–0.5–2.5	Contains acids that bind nutrients. Improves soil structure and water retention. Contains natural plant hormones.
Langbeinite (Sul–Po–Mag)	Potassium, magnesium	0–0–22; 11% magnesium.	Also called magnesium-bearing potassium sulphate. To avoid excessive magnesium levels, do not use if dolomitic limestone is used.
Limestone, calcitic	Raises pH, adds calcium	65–80% calcium carbonate; 3–15% magnesium carbonate	Use to 'sweeten' acidic soils where magnesium levels are adequate.
Limestone, dolomitic	Raises pH, adds calcium and magnesium	51% calcium carbonate; 40% magnesium carbonate	Use only where there is a magnesium deficiency, otherwise use calcitic limestone.
Oyster shells	Calcium	33.5% calcium.	Contain calcium carbonate.
Phosphate, colloidal	Phosphorous	0–2–0 16% phosphate, contains calcium, silicates & 14 micronutrients	More immediately available than rock phosphate.
Phosphate, rock	Phosphorous	0–3–0 32% total; phosphate 32% calcium, 10% silicas; micronutrients	Ask suppliers to provide metal content to ensure the rock phosphate does not contain high levels of heavy metals.
Wood ash [R]	Potassium	0–1.5–8; usually 80% calcium carbonate	Can add salts to the soil.
Worm castings	Organic matter	0.5–0.5–0.3	50% organic matter plus 11 micronutrients.

[R]: Restricted use under the Canadian Standard for Organic Agriculture. Contact certification body before application.

This table is based on a table from *The Real Dirt: farmers tell about organic and low–input practices in the northeast* (edited by Elizabeth Henderson and Miranda Smith, 1998). Reprinted with permission from the Northeast Region (USDA) Sustainable Agriculture Research and Education (SARE) Program and the Northeast Organic Farming Association (NOFA).
This table also contains information from Canada's *National Standard for Organic Agriculture* (CGSB, 1999: A1.1) and *The Soul of Soil* (Gershuny & Smillie, 1986).

APPENDIX I

Nutrient content and C: N ratio of compost and fresh manure from the Organic Field Crop Handbook (Wallace, 2001)

Composition of fresh manure

(produced by animals provided with ample bedding, on a wet-weight basis)

	Component of manure	Proportion of components		Nutrient content: Nitrogen (as N)		Nutrient content: Phosphorus (as P_2O_5)		Nutrient content: Potassium (as K_2O)	
		%	kg/t	%	kg/t	%	kg/t	%	kg/t
HORSE	Feces	60	600	0.55	3.3	0.30	1.8	0.40	2.4
	Urine	15	150	1.35	2.0	trace		1.25	1.9
	Bedding (straw)	25	250	0.50	1.3	0.20	0.5	1.00	2.5
	Total mixture	100	1000	0.66	6.6	0.23	2.3	0.68	6.8
COW	Feces	63	630	0.40	2.5	0.20	1.3	0.10	0.6
	Urine	27	270	1.00	2.7	trace		1.35	3.7
	Bedding (straw)	10	100	0.50	0.5	0.20	0.2	1.00	1.0
	Total mixture	100	1000	0.57	5.7	0.15	1.5	0.53	5.3
PIG	Feces	49	490	0.55	2.7	0.50	2.5	0.40	1.9
	Urine	33	330	0.60	2.0	0.10	0.3	0.45	1.5
	Bedding (straw)	18	180	0.50	0.9	0.20	0.4	1.00	1.8
	Total mixture	100	1000	0.56	5.6	0.32	3.2	0.52	5.2
SHEEP	Feces	60	600	0.75	4.5	0.50	3.0	0.45	2.7
	Urine	30	300	1.35	4.0	0.05	0.2	2.10	6.2
	Bedding (straw)	10	100	0.50	0.5	0.20	0.2	1.00	1.0
	Total mixture	100	1000	0.90	9.0	0.34	3.4	1.00	10.0

Source: "Manure and Compost", Agriculture Canada publication 868, by Maclean and Hore, 1979

Carbon:Nitrogen ratio (C:N) of compost materials

Dairy manure	20:1
Sheep manure	14:1
Poultry manure	10:1
Humus	10:1
Vegetable wastes	12:1
Seaweed	19:1
Straw	80:1
Corn stalks	60:1
Leaves	45:1
Alfalfa	13:1
Legume/grass hay	25:1
Grass hay	80:1
Rotted sawdust	200:1
Fresh sawdust	500:1
Newspaper	800:1

Mature compost

Amounts vary, but well-prepared mature compost may contain :

7.5–15 kg/tonne (15–30 lb/ton) nitrogen,

2.5–5 kg/tonne (5–10 lb/ton) phosphate and

15 kg/tonne (30 lb/ton) potash.

APPENDIX J

Characteristics of different cover crops and nitrogen content of some green manure from the Organic Field Crop Handbook (Wallace, 2001)

Matching cover crops with uses.
Examples of suitable cover crops for a variety of uses.

Use	Suitable cover crops	
Nitrogen-fixation	*excellent N-fixers:*	alfalfa, vetch, fava beans*, soybeans*
	moderate N-fixers:	sweetclover, alsike, berseem, crimson, white and red clover, field peas, birdsfoot trefoil
	in dry regions:	yellow sweetclover, Indianhead lentil, chickling vetch, black medic
Weed control	Ryegrass, buckwheat, fall rye, winter wheat, oilradish, mustard, crimson clover. Many legumes (e.g. alfalfa, sweetclover, subterranean clover, white clover, vetch) provide good weed control once they are established.	
Adding organic matter	Ryegrass, fall rye, oats	
Breaking up hardpans	Oilradish, sweetclover, red clover, alfalfa, lupins	
Ground cover	Ryegrass, hairy vetch, subclover, white clover	
Catch crops	*For summer catch crops:*	buckwheat, ryegrass, phacelia
	For fall catch crops:	oilradish, mustard, fall rye
Living mulches	White clover, subclover, ryegrass	
Bee plants	Buckwheat, all clovers, fava beans, sweetclover, phacelia	

* note that much of the nitrogen is removed if the beans are harvested.

Relative nitrogen contributions of various types of legumes.

Legume	Plant-nitrogen (%) derived from the atmosphere	Nitrogen fixed symbiotically kg/ha	lb/a
Alfalfa	80	300	267
Sweetclover	90	250	223
Fava beans	90	300	267
Field peas	80	200	178
Lentils	80	150	134
Soybeans	50	150	134
Chickpeas	70	120	108
Dry beans	50	70	62

Based on data from inoculated legumes grown under irrigation in Southern Alberta, from Green & Biederbeck (1995)