Exploring ecological sustainability in the production chain of organic eggs

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Wisdom becomes knowledge
when it becomes
your personal experience

-Yogi Bhajan-

Content

Chapter 1

General introduction

1.1. Objective

Ecological sustainability is a broad concept that unites ecological issues caused by human activities. Ecological issues generally associated with agriculture are: global warming, fossil energy depletion, land occupation, fossil phosphorus (P) depletion, acidification, eutrophication, soil depletion, biodiversity and eco-toxicity (Steinfeld et al., 2006). Agriculture inevitably affects the environment, because agriculture is a human activity taking place in the natural environment. Agriculture without an ecological impact, therefore, is a utopia. The integral ecological impact (i.e. impact along the production chain) of a production system, however, depends on its production characteristics. Production of one kg of organic milk, for example results in less eutrophication and fossil energy depletion, but more land use from cradle-to-farm-gate than production of one kg of conventional milk (De Boer, 2003; Thomassen et al., 2008). Organic agriculture has a specific perspective on sustainable agriculture, captured in their goal, definition and four principles of organic agriculture (see section 1.2; IFOAM, 2011). This perspective is converted to practical rules for organic production (EC, 1991; EC, 1999b). Producers receive an organic certificate if they produce according to these rules. In this thesis this specific perspective, i.e. IFOAM's goal, definition, principles and resulting rules, was referred to as the organic ethical framework. The organic ethical framework sets borders to the production characteristics of organic production systems. The ecological impact of organic production systems, therefore, may be affected by the organic ethical framework. The main objective of this thesis was to:

Assess the effect of the organic ethical framework on the integral ecological impact of Dutch organic egg production.

This objective was approached from three angles:

1. Determination of the difference in integral ecological impact of egg production with and without an organic ethical framework.
2. Identification of the main ecological issues in the current Dutch organic egg production system.
3. Exploration of options to improve integral ecological impact of Dutch organic egg production within the borders of the organic ethical framework.

We took the case of Dutch egg production, because a wide variety of egg products exists in the Netherlands with a large variation in ethical boundaries. Of these egg products organic egg production has the most confined ethical framework. The current diversity in egg production systems in the Netherlands, makes it possible to evaluate ecological performance among all relevant egg production systems in the EU, except for enriched cages.

1.2. Problem statement

Organic agriculture emerged at the start of the 20th century as a counter reaction to the industrial revolution. The industrial revolution heavily influenced agriculture through advances in biochemistry and (biological) engineering, such as the development of artificial fertilizers and tractors in the first half of the 20th century, and the development of pesticides, herbicides, antibiotics, hybrids, and genetically modified organisms in the second half of the 20th century. These advances increased efficiency in agriculture, because yields per ha increased and work load per unit of product decreased.

Negative side effects of these advances, however, soon became apparent: use of industrial resources in agriculture required much energy, i.e. contributed to depletion of fossil fuel and emissions of the greenhouse gas carbon dioxide (CO_2). Availability of cheap artificial fertilizer for crop cultivation and fossil fuel for transport of feed resulted in a split of arable and animal production. Manure turned from a valuable fertilizer into a polluting waste product and local overloads of manure started to occur. These overloads of nitrogen (N) and P resulted in acidification (e.g. ammonia (NH_3) emission), eutrophication (e.g. nitrate (NO_3^-) and phosphate (PO_4^-) leaching) and global warming (e.g. nitrous oxide (N_2O) emission). Furthermore, several pesticides, such as dichlorodiphenyltrichloroethane (DDT), were examined to be poisonous and heavy tractors appeared to cause soil compaction. These side effects triggered the reappearance of several traditional agricultural practices on which organic agriculture was based (Balfour, 1943; Carson 1962; Fukuoka, 1978; Howard, 1943; King, 1911; Northbourne, 1940; Steiner, 1924).

Organic agriculture was united in 1972 when the International Federation of Organic Agricultural Movements (IFOAM) was founded. The IFOAM's goal is: 'worldwide adoption of ecologically, socially and economically sound systems based on the principles of organic agriculture'. The four principles of organic agriculture are: health, ecology, fairness and care. They are defined by IFOAM as: 1) Health; organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible; 2) Ecology; organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them; 3) Fairness; organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities; 4) 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. The IFOAM's definition of organic agriculture is: 'a 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, 2011).

One of the requirements for organic hen husbandry is loose hen housing. Loose hen housing, however, results in higher emissions of NH_3, N_2O, and the greenhouse gas methane (CH_4) than hen housing in battery cages (Winkel et al., 2009; Mosquera et al., 2009; Fabbri et al., 2007). A sub-question of this thesis, therefore, was: What is the effect of loose hen housing on the integral ecological impact of Dutch organic egg production?

Currently, single-tiered housing is common in organic hen husbandry. In single-tiered hen houses, manure remains stored as litter on the floors and in the manure pit in the house until the end of the production round. In multi-tiered houses part of the manure is collected on manure belts, air-dried and frequently removed during the production round. As a result, emissions of NH_3, N_2O, and CH_4 from single-tiered houses is higher than from multi-tiered houses (Wathes et al., 1998). General adoption of multi-tiered houses may reduce the integral ecological impact of organic egg production. The integral ecological impact of multi-tiered housing instead of single-tiered housing in organic egg production, therefore, was a theme included in this thesis.

According to IFOAM organic agriculture should be based on closed nutrient cycles, i.e. organic manure should be recycled as a fertilizer for cultivation of crops. Ideally the nutrient cycle should be self-sufficient, i.e. non-organic manure would be prohibited. In a closed nutrient cycle retention of N and P in manure is vital. A share of N excreted by the laying hen, however, is emitted from the hen house. Besides inventorying the ecological impact of organic egg production, therefore, also the share of N excreted by the hen that emits from the hen house in different egg production systems and scenarios was determined.

Another requirement in organic hen husbandry is access of hens to an outdoor run (EC, 1991; EC, 1999b). In a natural ecosystem, the level of N and P in the soil is more or less balanced, because animals remove N and P by foraging on the vegetation and return most of this N and P in faeces and urine. In organic hen husbandry, however, excretion of N and P in the outdoor run generally exceeds the uptake by vegetation (Aarnink et al., 2006). Currently, N and P in manure droppings are not removed from the outdoor run by the farmers. Therefore, N and P dropped in the outdoor run will eventually be lost into the environment. These losses contribute to aquatic and terrestrial eutrophication, acidification and global warming (Steinfeld et al., 2006). Another sub-question of this thesis, therefore, was: What is the effect of presence of an outdoor run on the integral ecological impact of egg production and what is the share of total N and P excreted by the hen that is dropped in the outdoor run?

In organic agriculture use of external resources, that may obstruct ecological processes, biodiversity and cycles, should be avoided as much as possible. Currently prohibited external resources in organic agriculture are: artificial fertilizers, pesticides, herbicides, genetically modified organisms, and moreover only limited use of medication is allowed (EC, 1991; EC 1999b). Prohibition of these resources is expected to reduce the integral ecological impact, because the ecological impact caused by production and use of these resources is avoided. This reduction however, may be offset by a lower productivity of cultivation of diet ingredients (dry matter yield ha^{-1}) and hen husbandry (eggs hen^{-1} $year^{-1}$). For example, in organic agriculture crops are fertilized with manure instead of artificial fertilizer. This difference in resource use affects: yield per hectare, emissions of NH_3, N_2O, and nitrogen oxides (NO_x) from cultivation; N and P soil balances; fossil P use (i.e. artificial P fertilizer contains of fossil P); and fossil fuel use (i.e. production of artificial N fertilizer requires fossil fuel). Another sub-question of this thesis, therefore, was: What is the effect of exclusion of external resources on the integral ecological impact of Dutch organic egg production?

In 2005 the global organic agricultural area had grown to 26 million hectare spread over 110 countries (Willer and Yussefi, 2005). Land use for organic agriculture, however, was still less than 1% of total land use for agriculture (Steinfeld et al., 2006). Although organic products are produced worldwide, they are consumed mainly in Europe and North America. This indicates that organic products are often transported over large distances. In the case of Dutch organic egg production the agricultural nutrient cycle is disconnected. In 2011, there were 114 organic laying hen farms in the Netherlands with a total of 1.3 million laying hens. Cultivation of 98% of the diet ingredients for these hens, however, was located outside the Netherlands. Laying hen manure was not exported to countries that produce diet ingredients, but sold within the Netherlands and to Germany. Furthermore, use of fossil fuel causes major worldwide ecological concern, because burning of fuel emits CO_2 and depletion of fossil fuel will result in difficulties regarding energy supply of future generations (Steinfeld et al., 2006). A large distance between cultivation of diet ingredients and laying hen husbandry, therefore, conflicts with the principles of organic agriculture. Changing the location of cultivation of diet ingredients to the Netherlands seems a logical solution to this problem. This change, however, affects the whole egg production system. First, production characteristics of cultivation depend on local circumstances. Second, some of the diet ingredients need to be exchanged, because these ingredients cannot be cultivated in the Netherlands and third, a change of diet composition affects feed intake and egg production. The last sub-question included in this thesis, therefore, was: What is the ecological impact of cultivation of diet ingredients in the Netherlands compared with current Dutch organic egg production?

1.3. Outline of the thesis and methodology

In chapter 2 the integral ecological impact of current Dutch organic and non-organic egg production was assessed. In chapter 3 emission of NH_3, N_2O and CH_4 from organic multi-tiered houses was quantified. In chapter 4 loss and distribution of N and P to the outdoor run was quantified. In chapter 5 the integral ecological impact was assessed of replacing currently imported concentrate ingredients with nutritional comparable regional ingredients for Dutch organic egg production. In chapter 6 the overall results of the thesis were discussed, general conclusions were drawn and recommendations were made.

The objective of chapter 2 was to quantify the ecological and economic performance of the most commonly used egg production systems in the Netherlands, and identify which parameters explain differences in performance among systems. We included the conventional battery cage system and the following loose housing systems: single and multi-tiered barn systems, single and multi-tiered free range systems, and single and multi-tiered organic systems. An ecological scale for egg production was set. To explore the integral ecological impact life cycle assessment (LCA) was used. An LCA allows evaluation of different ecological issues simultaneously and comparison of products that originate from different production systems. An LCA starts with the definition of the boundary of the production system and the corresponding functional unit. The functional unit is the main product of interest of the analysed system in quantitative terms, and was defined in this study as one kg of eggs leaving the farm gate. Processes included in this LCA of egg production systems were: production of diet and litter (i.e. sand and organic wheat straw used as bedding material), hatching, rearing and laying hen husbandry and transport. Egg production systems were assessed based on nine ecological indicators, all expressed per kg of egg, i.e. global warming potential, energy use, land occupation, acidification potential, fossil P use, N deficit, P deficit, N surplus and P surplus.

The objective of chapter 3 was to measure the year round emissions of NH_3, N_2O, and CH_4 from three commercial multi-tiered systems with organic laying hen husbandry. Emission rates of NH_3, N_2O, and CH_4 were calculated by multiplying the absolute difference between outside and inside concentrations of NH_3, N_2O, and CH_4 with the ventilation rate. Ventilation rate was calculated with the CO_2 mass balance method. The option to reduce emission of NH_3, N_2O, and CH_4 with a shorter interval of removal of manure from manure belts was explored. Furthermore, the share of N lost from litter and belt manure was estimated. This share was estimated by comparison of N and P composition of faeces and manure samples.

The objective of chapter 4 was to determine level and variation of load of N and P in the outdoor run and the total mass of N and P excreted into the outdoor run of three commercial organic laying hen farms. Loss and distribution of N and P were determined indirectly by measuring: content of N and P of manure; mass of the freshly excreted manure dropping; rate of production of droppings by hens in the outdoor run; and total number and distribution of hens in the outdoor run.

The objective of chapter 5 was to assess the potential to reduce the integral ecological impact of Dutch organic egg production by replacing currently used imported diet ingredients with Dutch diet ingredients. This objective was realized by comparing the LCAs of current Dutch organic egg production with different scenarios. In each scenario, one imported diet ingredient was replaced with a diet ingredient produced in the Netherlands. Finally, a scenario was formulated in which several ingredients, that individually resulted in the lowest mean change in ecological impact along the organic egg production chain, were replaced simultaneously.

Chapter 2

Ecological and economic evaluation of Dutch egg production systems

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Abstract

The upcoming ban on battery cages in the European Union is expected to cause a shift in husbandry systems from predominantly battery cages to enriched cages and loose housing systems, such as barn, free range and organic systems. To gain insight into ecological and economic consequences of such a ban, we quantified the ecological and economic performance of the most commonly used egg production systems in the Netherlands, and identified which parameters explain differences in performance. We included the conventional battery cage system and the following loose housing systems: single and multi-tiered barn systems, single and multi-tiered free range systems, and single and multi-tiered organic systems. Ecological indicators used were deduced from a life cycle assessment, and were: global warming potential, energy use, land occupation, fossil phosphorus use, acidification potential, nitrogen and phosphorus deficit, and nitrogen and phosphorus surplus, each expressed per kg of egg. Economic indicator used was net farm income per full time employee. Based on our ecological evaluation of Dutch egg production systems, we predict that a ban on battery cages in the European Union will increase global warming potential, land occupation and acidification potential per kg of egg produced, whereas the effect on energy use, fossil phosphorus use, nitrogen and phosphorus deficit, and nitrogen and phosphorus surplus depends on relative importance of different loose housing systems. Of all loose housing systems, organic systems had lowest global warming potential, energy use, fossil phosphorus use, and nitrogen and phosphorus surplus, whereas land occupation and nitrogen and phosphorus deficit was lowest for barn systems. Acidification potential was lowest for a multi-tiered barn system. Differences in life cycle assessment results among production systems can be explained mainly by differences in; feed conversion, in parameters that determine ecological impact per kg feed ingredient (e.g. crop yield per ha; number of field operations, type and amount of fertilization), drying of grain, transport of concentrates and manure, type of hen house and Nitrogen excretion per hen per year. Free range systems had highest net farm income, followed by organic systems. Multi-tiered systems had a higher net farm income than single-tiered systems. In case differences among egg and cost prices of different systems do not change after a ban on the battery cage, multi-tiered free range and organic systems are economically most favorable.

Abbreviations	
B	battery cage housing
eq.	equivalents
EU	European Union
FTE	full time employee
GM	gross margin
LCA	life cycle assessment
M	multi-tiered housing
NFI	net farm income
PHR^{-1}	per purchased hen per round
S	single-tiered housing

2.1. Introduction

The European Union (EU) recognizes that welfare of laying hens should be improved, but remarked that this improvement should be in balance with the three domains of sustainability: social, ecological, and economic sustainability (EC, 1999a). To improve the social issue of welfare of laying hens, the EU decided that egg production in battery cages will be banned from 2012 onwards (EC, 1999a). These two statements raise the following question: what effect does a ban on battery cages have on the ecological and economic performance of the egg production sector?

Currently, a wide range of egg production systems exists in Europe. These systems develop within the boundaries of social acceptance, which are established by legislation and product certification. EU legislation prescribes, for example, that each hen requires a minimum available surface of 550 cm^2 for battery cage housing, 1111 cm^2 for loose housing (EC, 1999a), and 1666 cm^2 for organic housing (EC, 1999b). Each organic and free range hen, furthermore, should be offered 4 m^2 of outdoor run (EC, 1999b). Dutch legislation, moreover, prescribes that each organic rearing hen requires a minimum available surface of 1000 cm^2 indoors and 1 m^2 outdoors (SKAL, 2009). EU legislation on organic egg production also allows only limited use of additives and curative medicines and forbids use of artificial fertilizer, pesticides, herbicides and genetically modified organisms (EC, 1991; EC, 1999b). In addition, as a reaction to EU legislation, Dutch legislation states that farms with more than 40,000 hens should implement the best available techniques to reduce NH_3 emission (VROM, 2005). An exception to this rule, however, is made for organic farming. Regarding product certification the EU regulates four categories of table eggs: 0 or organic, i.e. organic certified loose housing with outdoor access; 1 or free range, i.e. loose housing with outdoor access; 2 or barn, i.e. loose housing without outdoor access; and 3 or battery, i.e. caged housing (EC, 1990).

In 2006, about 78% of eggs in the EU were still produced in battery cages (Anonymous, 2008). In the Netherlands, however, because retailers have stopped selling table eggs from battery cages under pressure of animal rights organizations, the market share of eggs from loose housing systems has already increased from 8% in 1990 to 52% in 2009. In 2009, 48% of Dutch eggs were produced by hens in a battery cage system, 37% by hens in a barn system, 13% by hens in a free range system and 2% by hens in an organic system. Statistics from 2008 showed that hens in loose housing systems were about equally divided over single-tiered (48%) and multi-tiered (52%) systems (CBS, 2010; PVE, 2010). In the Netherlands, enriched battery cages, i.e. cages with adjustments to improve laying hen welfare, described in Dutch legislation as housing type E 1.5.5 (VROM, 2010) have not been publicly and politically accepted (Windhorst, 2006), and, therefore, only a few farms have enriched battery cages. The current diversity in egg production systems in the Netherlands, therefore, makes it possible to evaluate ecological and economic performance among all relevant egg production systems in the EU, except for enriched cages.

Each egg production system has strengths as well as weaknesses, regarding sustainability. The shift in egg production systems away from battery cages will not only affect welfare of laying hens, but will affect other sustainability issues also, such as climate change, use of fossil fuel, acidification, eutrophication, and profitability. An assessment of the ecological and economic performance of current Dutch systems should give insight into the ecological and economic consequences of the upcoming ban on battery cages. Mollenhorst et al. (2006) evaluated the ecological and economic performance of only a part of the existing Dutch egg production systems, whereas Williams et al. (2006) determined the ecological performance of the entire egg production sector in UK, without differentiating among housing systems. Mollenhorst et al. (2006) and Williams et al. (2006), moreover, did not identify "ecological hotspots", i.e. stages of the production chain (subsystems) or polluting substances with a major impact. A complete evaluation of ecological and economic performance of current egg production systems is absent. A detailed cause and effect assessment is necessary to point out the strengths and weaknesses of each egg production system. Such an evaluation gives insight into possible future ecological and economic effects of the EU ban on battery cages. The objective of this research, therefore, was to quantify the ecological and economic performance of the most commonly used egg production systems in the Netherlands, and to identify which parameters explain differences in performance among systems. We included the conventional battery cage system, single and multi-tiered barn systems, single and multi-tiered free range systems, and single and multi-tiered organic systems. In a single-tiered system hens live on one floor level, which is partially tiered (i.e. housing type E 2.7 (VROM, 2010)), whereas in a multi-tiered system hens live on multiple floor levels, which are partially tiered (i.e. housing type E 2.11.1 (VROM, 2010)).

2.2. Materials and methods

2.2.1. Ecological performance

The ecological performance of the seven egg production systems was evaluated by life cycle assessment (LCA). LCA is an integral method that evaluates the ecological impact resulting from the entire life cycle of a product (Guinée et al., 2002). LCA allows evaluation of different ecological issues simultaneously and identification of major polluting substances and processes along a production chain.

LCA starts with the definition of the boundary of the production system (Fig. 2.1), and the corresponding functional unit. The functional unit is the main product of interest of the analysed system in quantitative terms, and was defined here as 1 kg of eggs leaving the farm gate. Subsequently, LCA relates the ecological impact of the defined production system to the functional unit. Processes included in this egg production system were: production of concentrates and litter (i.e. sand and organic wheat straw used as bedding material), hatching, rearing and laying hen husbandry and transport. Some of these processes resulted in a multiple outputs: laying hen husbandry, for example, yields eggs and slaughter hens, whereas oil pressing of soy beans yields oil and soy bean expeller. Economic allocation was used to divide the ecological impact among multiple outputs. We assumed an economic value of zero for poultry manure.

To identify which part of the production chain contributed most to LCA results, the entire egg production chain was divided in three subsystems (Fig. 2.1); 1) concentrate and litter production; 2) rearing hen husbandry (including hatching), and 3) laying hen husbandry. Furthermore, the impact related to transport of inputs and outputs of these subsystems was considered a fourth subsystem; 4) transport.

Each egg production system was evaluated based on nine ecological indicators, expressed per kg of egg: global warming potential, energy use, land occupation, fossil phosphorus use, acidification potential, nitrogen (N) deficit, phosphorus (P) deficit, N surplus and P surplus. Substances that contribute to each of these indicators were inventoried per kilogram of egg for processes included in the entire production chain. Substances were summed using equivalence factors. Use of equivalence factors enables summation of different contributing substances into one common unit. For the ecological indicator global warming potential, for example, we computed the emission of the gases CO_2, CH_4, and N_2O from processes in the entire egg production chain, such as CO_2 emission from combustion of fossil fuel, CH_4 emission from manure storage and N_2O emission from fertilizer application. Global warming potential was the sum of these three greenhouse gases, based on IPCC (2006) equivalence factors, i.e. 1 for CO_2, 25 for CH_4 and 298 for N_2O, and was expressed in g CO_2-equivalents per kg of egg. Ecological indicators, their unit, contributing substances and equivalence factors included in this LCA are listed in Table 2.1. The indicators N and P surplus, and N and P deficit were computed separately and cannot be summed because N and P surplus refer to soil eutrophication, whereas N and P deficit refer to depletion of NP from the soil. Soil eutrophication and depletion may occur at different locations in one production chain. Production of organic feed ingredients, for example, may result in soil depletion, whereas in the outdoor run soil eutrophication may occur.

2.2.2. Technical data required for ecological performance

Data were collected for 2006 and 2007. The ecological impact related to transport, industrial processes (e.g. milling or drying), field operations (e.g. sowing or harvesting), production and use of fossil energy, and production of artificial fertilizers, of pesticides, of water and lime, were obtained from Ecoinvent v2.0 (Ecoinvent, 2007). In the following paragraphs we describe computation of ecological impact caused by the four subsystems: concentrate and litter production, hatching and rearing hen husbandry, laying hen husbandry and transport.

Subsystem: concentrate and litter production

The ecological impact of concentrate production included the impact related to cultivation and processing of its main arable feed ingredients (Table 2.2), the impact related to processing of concentrates, and the impact related to the production process of the feed ingredient lime (i.e. 11% of laying hen concentrates). The exact feed composition differed for conventional rearing hens, organic rearing hens, conventional laying hens, and organic laying hens. For conventional concentrates, feed composition was based on Mollenhorst (2005), whereas for organic concentrates, feed composition was based on interviews with two organic feed companies. The impact related to feed processing was based also on these interviews, and was assumed equal for all concentrates. Per ton concentrates, feed processing used: 13.5 kWh electricity, 0.5 m^3 natural gas, and 0.032 m^2 land per year.

Ecological impact of crop cultivation included impacts related to production and use of seed, artificial fertilizer, manure, pesticides, field operations and irrigation. Harvesting and optional industrial processing could yield multiple products, such as wheat grain and straw, or soy oil and expeller. During production of wheat as feed ingredient, no straw was harvested. Economic allocation percentages used in multiple output are in

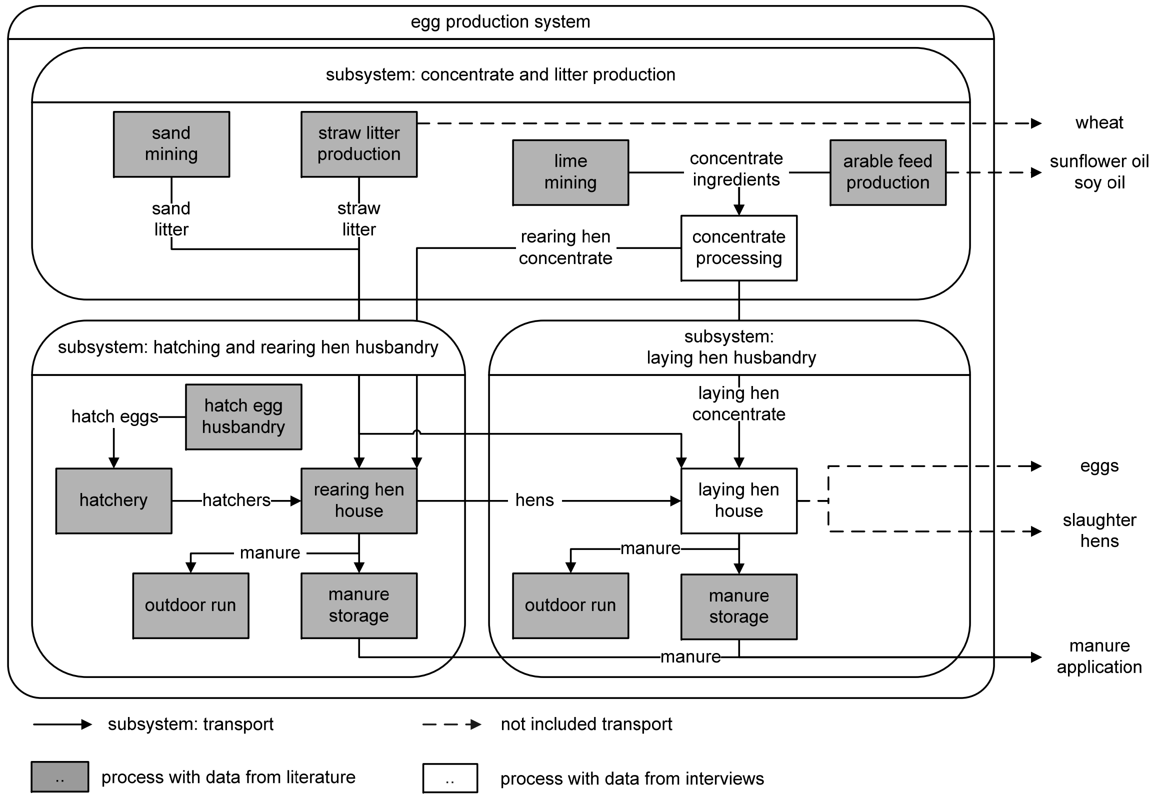

Figure 2.1 Boundary of the egg production system evaluated and the four subsystems considered: concentrate and litter production, hatching and rearing hen husbandry, laying hen husbandry and transport.

Table 2.1 Specification of the selected ecological indicators, their units, contributing substances, their equivalence (eq.) factors and their units.

Ecological indicator	(unit)	Substance	Eq. factor	(unit)
Global warming potential	(g CO_2 eq. kg^{-1} egg)	CO_2	1	(g CO_2 eq. g^{-1} CO_2)
		CH_4	25	(g CO_2 eq. g^{-1} CH_4)
		N_2O	298	(g CO_2 eq. g^{-1} N_2O)
Energy use	(MJ kg^{-1} egg)	Oil	43.4	(MJ kg^{-1} oil)
		Gas	40.1	(MJ kg^{-1} gas)
		Coal	18.7	(MJ kg^{-1} coal)
		Uranium	1.4 10^6	(MJ kg^{-1} uranium)
Land occupation	(m^2 $year^{-1}$ kg^{-1} egg)	Land use	1	(m^2 y^{-1})
Fossil P use	(g P kg^{-1} egg)	Fossil P	1	(g P)
Acidification potential	(g SO_2 eq. kg^{-1} egg)	SO_2	1	(g SO_2 eq. g^{-1} SO_2)
		SO_x	1.2	(g SO_2 eq. g^{-1} SO_x)
		NH_3	1.9	(g SO_2 eq. g^{-1} NH_3)
		NO_x	0.7	(g SO_2 eq. g^{-1} NO_x)
N deficit	(g N kg^{-1} egg)	Soil N	1	(g N)
P deficit	(g P kg^{-1} egg)	Soil P	1	(g P)
N surplus	(g N kg^{-1} egg)	Soil N	1	(g N)
P surplus	(g P kg^{-1} egg)	Soil P	1	(g P)

Table 2.3. Assumptions regarding crop cultivation and economic allocation were based on the literature and expert consultation (CVB, 2008; Ecoinvent, 2007; FAO, 2002, 2004, 2005; KWIN-AGV, 2007; KWIN-V, 2007).

For each arable crop used as feed ingredient, the surplus and deficit of N and P were computed as the difference between the NP input to the field minus the NP output from the field. Field inputs of NP were: NP in manure, NP in artificial fertilizer, N deposition, N fixation and NP in seed, whereas field outputs of NP were: NP in yielded products and N emissions (e.g. ammonia (NH_3), N_2O, NO_x). Emission of NH_3-N was computed according to IPCC (2006) as a fixed percentage of artificial fertilizer N (10%) and manure N (20%) applied. Direct emission of N_2O-N from crop fields were computed as 0.75% of N in crop residues and 1% of N in manure and artificial fertilizer (IPCC, 2006), whereas NO_x-N field emissions were 21% of the direct N_2O-N emission (Ecoinvent, 2007). Indirect N_2O-N emissions were computed as 1% of emission of NH_3-N and 0.75% of leached nitrate (NO_3^-)-N (IPCC, 2006).

Two types of litter were used in rearing and laying hen husbandry, i.e. sand and organic wheat straw (Table 2.3). The ecological impact of production of sand was based on Ecoinvent v2.0 (Ecoinvent, 2007), whereas the impact of organic wheat straw was computed in the same way as the impact assessment of arable feed ingredients, as described above (Table 2.2).

Subsystems: hatching, rearing hen husbandry and laying hen husbandry

Inputs of the hatchery included hatch eggs, electricity (0.055 kWh $hatcher^{-1}$), tap water (0.55 l $hatcher^{-1}$), natural gas (0.003 m^3 $hatcher^{-1}$) and land (1.1 cm^2 year $hatcher^{-1}$), whereas the output was hatchers, i.e. a newly hatched chick (KWIN-V, 2007). Production data of hens used to produce hatch eggs were assumed to equal data of hens housed in a single-tiered barn system.

We assumed that rearing and a laying hens in battery cages were housed in a four to five tiered battery cage (i.e. housing types E 1.5.2 and E 2.5.2 (VROM, 2010)), with forced air drying of manure at a minimum ventilation rate of 0.4 m^3 per hen per hour for rearing hens and 0.7 m^3 per hen per hour for laying hens. All manure from the battery cage was removed every five days, implying a dry matter content of manure of over 55%. Rearing and laying hens in a single-tiered loose housing system (barn, free range and organic) had 66% slatted floors (i.e. housing types E 1.7 and E 2.7 (VROM, 2010)). All manure was assumed to remain in the hen house until the end of the production period. Rearing and laying hens in a multi-tiered loose housing system had 50% slatted floors, in two or more tires, with a manure belt (i.e. housing types E 1.8.1 and E 2.11.1 (VROM, 2010)). We assumed that 70% of the manure was removed every seven days with manure belts (CBS, 2010; VROM, 2010), whereas 30% of the manure remained in the hen house until the end of the production period. Manure from belts was assumed to be transported to Dutch arable farms, because of its high N content, whereas manure that remained in the hen house was assumed to be transported to German farms, because of its low N content.

We, furthermore, assumed that rearing and laying hens were housed in the same type of husbandry system, with one exception: free range hens had access to an outdoor run during laying hen husbandry, but not during rearing hen husbandry.

Production data, farm inputs and farm outputs for rearing hens in barn, free range or organic systems were based on KWIN-V (2007) and assumed similar to each other. For laying hens in battery cages, barn and free range housing systems, this information was based on KWIN-V (2007), and expert consultation (Table 2.3). For organic laying hen husbandry, this information was obtained from interviews of 20 randomly selected organic farmers, except for land use which was based on KWIN-V (2007), for the hen house, and on SKAL (2009), for the outdoor run. Electricity use of different housing systems was based on Van Horne (1994).

To assess the ecological impact from manure excreted by rearing and laying hens, we computed emission of NH_3, N_2O, NO_x and CH_4 from manure present in the compartments: hen house, outdoor run, and manure storage. In addition, we computed N and P surplus in the outdoor run (Fig. 2.2). To assess emission of NH_3, N_2O and NO_x, we computed for each husbandry system the total N excretion of a hen as the amount of N in concentrates minus the amount of N in eggs and growth. Information on NP content of conventional concentrates and organic rearing hen concentrates, eggs, and slaughter hens was based on Jongbloed and Kemme (2005) and was assumed equal for all production systems (Table 2.3). The NP content of organic laying hen concentrates (Table 2.2) was based on Dekker et al. (2010). The amount of manure N present in the hen house and outdoor run was computed as a percentage of total N excretion, i.e. 1% of excreted N in the outdoor run for rearing hen husbandry and 4.3% for laying hen husbandry (Dekker et al., 2010). Emission of N from the hen house and outdoor run were computed as a fixed percentage (Table 4) of the amount of manure N present (Groenestein et al., 2005), including ecological neutral emission of nitrogen gas (N_2). The amount of N present in manure storage was computed as the difference between N present in the hen house minus N emissions from the hen house. Emissions of N from manure storage were computed also as a fixed percentage (Table 2.4) of the amount of manure N present (Groenestein et al., 2005), including ecological neutral emission of N_2. Finally, N surplus of the outdoor run was computed as the difference between N present in the outdoor run minus N emissions from the outdoor

Table 2.2 (a) Production data, energy use and NP balance of conventional and organic concentrate ingredients and organic wheat straw litter per hectare and per cultivation round.

	(unit)	Feed ingredient				
		Conventional				
		Grain maize	Wheat	Wheat	Soybean exp.[a]	Sunflower exp.[a]
Production data						
Producing country		France	France	Germany	Brazil	Argentina
Rearing hen concentrate share	(%)	41	20	20	12	8
Laying hen concentrate share	(%)	42	11	11	17	7
Dry matter content	(%)	87	87	87	89	91
Economic allocation	(%)	100	100	100	59	48
Seed	(kg ha^{-1})	25	180	158	70	3
Main yield[c]	(kg ha^{-1})	8,792	6,753	7,567	1,928	1,092
Co-yield	(kg ha^{-1})	-	-	-	616[d]	308[d]
Energy use						
Field operation	(MJ ha^{-1})	7,828	10,797	10,249	7,361	3,864
Fertilizer/pesticide production	(MJ ha^{-1})	10,215	20,622	13,504	2,935	815
Irrigation	(MJ ha^{-1})	4,040	-	-	-	-

Drying	(MJ ha^{-1})	27,200	-	2,150	-	2,690
Processing	(MJ ton^{-1})	169	169	169	368	1,074
Transport over land	(km)	806	806	625	234	234
Transport over water	(km)	-	-	-	9,785	11,808
NP balance						
Manure/artificial fertilizer N	(kg N ha^{-1})	199.80	198.00	174.00	8.46	10.00
Other N[e]	(kg N ha^{-1})	15.73	18.98	18.54	186.93	15.47
Yield N	(kg N ha^{-1})	115.00	134.00	151.00	143.00	31.40
Emission NH_3-N	(kg N ha^{-1})	25	19.80	17.40	0.85	1.00
Emission N_2O-N	(kg N ha^{-1})	3.56	3.53	3.08	0.73	0.28
Emission NO_x-N	(kg N ha^{-1})	0.34	0.35	0.33	0.04	0.03
N deficit/surplus	(kg N ha^{-1})	71.63	59.30	20.73	50.78	-7.23
Manure/artificial fertilizer P	(kg P ha^{-1})	38.00	71.90	56.20	28.80	3.05
Seed P	(kg P ha^{-1})	0.07	0.61	0.54	0.37	0.01
Yield P	(kg P ha^{-1})	23.70	23.00	25.70	13.47	6.02
P deficit/surplus	(kg P ha^{-1})	14.37	49.51	31.04	15.70	-2.96

Table 2.2 (b) Production data, energy use and NP balance of conventional and organic concentrate ingredients and organic wheat straw litter per hectare and per cultivation round.

	(unit)	Feed ingredient				Litter
		Organic				Organic
		Grain maize	Wheat	Soybean exp.[a]	Sunflower exp.[a]	Wheat straw
Production data						
Producing country		Italy	Ukraine	Brazil	Ukraine	NL[b]
Rearing hen concentrate share	(%)	41	10	12	8	-
Laying hen concentrate share	(%)	46	31	12	-	-
Dry matter content	(%)	87	87	89	91	87
Economic allocation	(%)	100	100	74	54	11
Seed	(kg ha^{-1})	25	200	70	3	200
Main yield[c]	(kg ha^{-1})	9,700	2,500	2,003	894	3,000
Co-yield	(kg ha^{-1})	-	-	247[d]	196[d]	5,000[e]
Energy use						
Field operation	(MJ ha^{-1})	9,508	5,613	9,164	4,608	947
Fertilizer/pesticide production	(MJ ha^{-1})	-	-	-	-	-
Irrigation	(MJ ha^{-1})	4,040	-	-	-	-

Drying	(MJ ha^{-1})	22,500	-	-	2,690	-
Processing	(MJ ton^{-1})	169	169	198	988	169
Transport over land	(km)	1,209	489	234	489	100
Transport over water	(km)	90	6,544	9,785	6,544	-
NP balance						
Manure/artificial fertilizer N	(kg N ha^{-1})	83.60	25.60	-	-	128.00
Other N[e]	(kg N ha^{-1})	15.73	19.38	167.23	15.47	35.48
Yield N	(kg N ha^{-1})	127.00	49.80	126.00	24.40	99.50
Emission NH_3-N	(kg N ha^{-1})	16.70	5.12	-	-	16.60
Emission N_2O-N	(kg N ha^{-1})	1.84	0.70	0.52	0.14	2.06
Emission NO_x-N	(kg N ha^{-1})	0.20	0.07	0.03	0.02	0.22
N deficit/surplus	(kg N ha^{-1})	-46.42	-10.71	40.68	-9.08	45.10
Manure/artificial fertilizer P	(kg P ha^{-1})	24.30	7.20	-	-	36.00
Seed P	(kg P ha^{-1})	0.07	0.68	0.37	0.01	0.68
Yield P	(kg P ha^{-1})	26.20	8.50	11.90	4.96	17.00
P deficit/surplus	(kg P ha^{-1})	-1.83	-0.62	-11.53	-4.68	19.68

[a] exp. = expeller, [b] NL = Netherlands, [c] After drying and expeller processing, [d] Oil, [e] Wheat.

Table 2.3 Production data, farm inputs and farm outputs of rearing hen husbandry and laying hen husbandry for battery cage (B), barn, free range and organic production systems in single (S) and multi-tiered (M) housing.

	(unit)	Rearing hen husbandry			Laying hen husbandry			
		Battery cage	Barn	Organic	Battery cage	Barn	Free range	Organic
Production data								
Round duration	(days)	119	119	119	420	406	396	398
Feed conversion	(kg kg^{-1})	-	-	-	1.99	2.28	2.33	2.59
N-content concentrate	(g kg^{-1})	24	24	24	25	25	25	29
P-content concentrate	(g kg^{-1})	5.6	5.6	5.6	4.6	4.6	4.6	4.6
Density house[a] B	(hen m^{-2})	45.5	-	-	25.0	-	-	-
Density house[a] S	(hen m^{-2})	-	14.1	9.4	-	8.6	8.6	5.6
Density house[a] M	(hen m^{-2})	-	30.3	18.9	-	20.4	16.1	8.1
Density outdoor run	(hen m^{-2})	-	-	1.00	-	-	0.25	0.25
Weight egg	(g)	-	-	-	62.4	62.5	62.5	62.7
N-content egg	(g kg^{-1})	-	-	-	19	19	19	19
P-content egg	(g kg^{-1})	-	-	-	1.7	1.7	1.7	1.7
Weight rear hen	(kg)	0.04	0.04	0.04	1.40	1.52	1.52	1.52
Weight slaughter hen	(kg)	1.40	1.52	1.52	1.72	1.80	1.80	1.94
N-content hen	(g kg^{-1})	29	29	29	28	28	28	28
P-content hen	(g kg^{-1})	4.5	4.5	4.5	5.5	5.5	5.5	5.5

Farm inputs and resources								
Concentrates	(kg PHR^{-1})[b]	5.3	5.8	6.6	42.0	45.3	43.9	44.9
Sand litter	(kg PHR^{-1})[b]	-	0.2	0.2	-	0.2	0.2	0.2
Straw litter	(kg PHR^{-1})[b]	-	-	0.2	-	-	-	0.4
Tap water	(l PHR^{-1})[b]	10	10	12	80	80	80	77
Electricity B	(kWh PHR^{-1})[b]	0.73	-	-	3.67	-	-	-
Electricity S	(kWh PHR^{-1})[b]	-	0.73	0.58	-	1.33	1.29	1.50
Electricity M	(kWh PHR^{-1})[b]	-	0.73	0.58	-	1.35	1.31	1.77
Natural gas	(m^3 PHR^{-1})[b]	0.15	0.15	0.38	-	-	-	-
Farm outputs								
Eggs	(nr PHR^{-1})[b]	-	-	-	338	318	302	276
Hens	(nr PHR^{-1})[b]	0.96	0.96	0.96	0.93	0.91	0.89	0.87
Manure	(kg PHR^{-1})[b]	2	2	2	18	18	18	18

[a] density = the number of hens in the hen house divided by the total surface of the building.
[b] PHR^{-1} = per purchased hen per round.

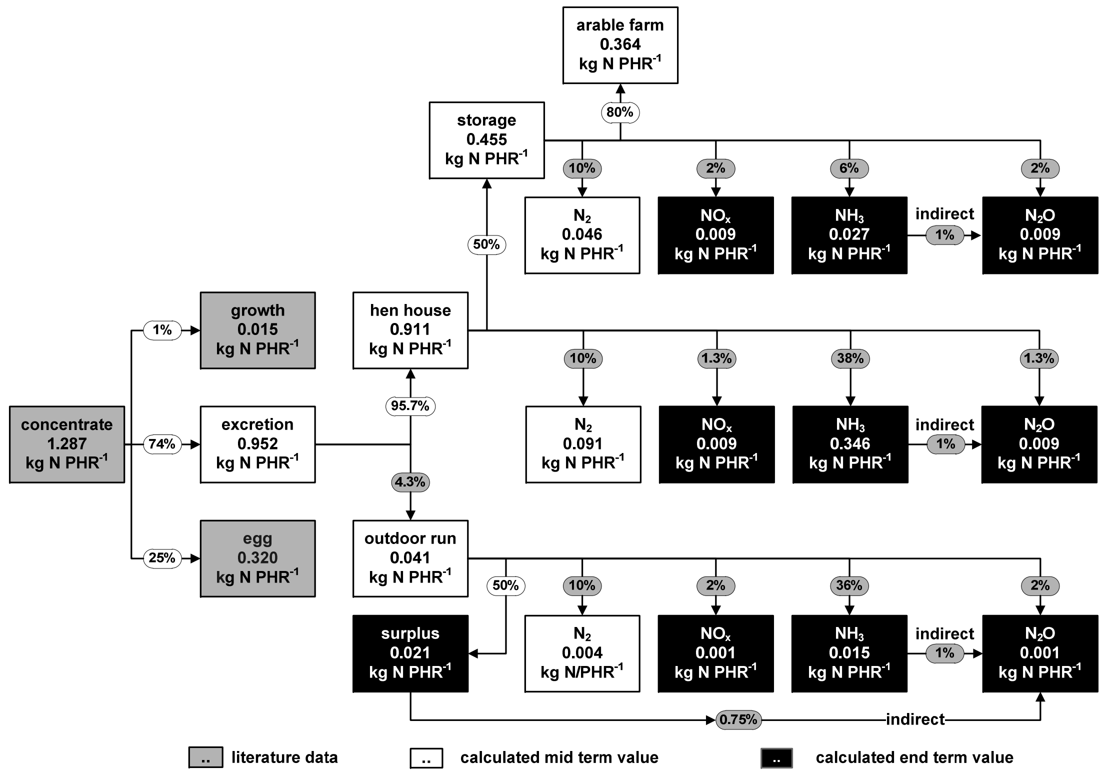

Fig. 2.2 N balance calculation method used for N emissions from organic single-tiered laying hen husbandry, N input in kg N per purchased hen per round (PHR), percentages represent the partial N flow from one compartment into the next compartment.

run. In addition to direct N_2O emission from compartments, we also included indirect N_2O emission from emitted NH_3 (1%) and N surplus (0.75%) based on IPCC (2006). To determine P surplus a simplified approach was used, as gaseous P emissions do not exist. To account for actual amount of manure present in each compartment, CH_4 emission was computed as a percentage of N excretion (Table 2.4) in each compartment.

Despite small differences in prices of eggs and slaughter hens among systems, economic allocation was 99% for eggs and 1% for slaughter hens for each production system.

Table 2.4 N_2-N, NO_x-N, NH_3-N, N_2O-N and CH_4 emissions as a percentage of the N present in the compartments: battery cage hen house, single-tiered hen house, multi-tiered hen house, outdoor run and manure storage for rearing hens and laying hens.

		N_2-N (%)	NO_x-N (%)	NH_3-N (%)	N_2O-N (%)	CH_4 (%)
Battery cage	Rearing hen husbandry	1	0.1	2	0.1	3.4
	Laying hen husbandry	1	0.1	2	0.1	3.4
Single-tiered	Rearing hen husbandry	10	1.6	45.4	1.6	6.2
	Laying hen husbandry	10	1.3	38	1.3	5.3
Multi-tiered	Rearing hen husbandry	1	1.1	13.5	1.1	4.2
	Laying hen husbandry	1	1.1	12	1.1	4.1
Outdoor run	Hen husbandry	10	2.0	36	2.0	3.4
Manure storage	Hen husbandry	10	2.0	6	2.0	0.4

Data on emissions from hen house, outdoor run, and manure storage facility were based on Mosquera et al. (2009), Winkel et al. (2009a,b), and Oenema et al. (2000).

Subsystem: Transport

This subsystem includes transport of hatchers, rearing hens, litter, hen manure, concentrates and concentrate ingredients. Based on farm interviews, we assumed transport distance over land of 101 km for purchased rearing hens, of 10 km for purchased litter and of 86 km for transport of concentrates

Table 2.5 Prices of inputs and outputs, hens per FTE, and investment per full time employee (FTE^{-1}) of battery cage (B), single (S) and multi-tiered (M) barn, single and multi-tiered free range and single and multi-tiered organic hen husbandry.

	(unit)	B	Barn		Free range		Organic	
			S	M	S	M	S	M
Hens per FTE	(nr FTE^{-1})	60,000	25,000	35,000	25,000	30,000	8,000	12,000
Egg price	(€ kg^{-1})	0.72	0.86	0.86	1.01	1.01	1.72	1.72
Slaughter hen price	(€ kg^{-1})	0.12	0.12	0.12	0.12	0.12	0.16	0.16
Concentrate price	(€ kg^{-1})	0.2	0.2	0.2	0.2	0.2	0.34	0.34
Rearing hen price	(€ hen^{-1})	3.1	3.5	3.5	3.6	3.6	6.02	6.02
Other variable costs [a]	(€ PHR^{-1})	1.58	1.51	1.51	1.59	1.59	1.22	1.44
General fixed costs [b]	(€ FTE^{-1} y^{-1})	16,500	16,500	16,500	16,500	16,500	16,500	16,500
Building and silo investment	(€ FTE^{-1})	437,572	631,000	394,888	631,000	339,334	304,886	317,688
Equipment investment	(€ FTE^{-1})	820,201	382,700	663,254	382,700	578,534	160,943	360,065
Land investment	(€ FTE^{-1})	45,000	45,000	45,000	435,000	513,000	170,000	232,000
Other investments [c]	(€ FTE^{-1})	2,200	1,750	2,200	18,450	22,240	7,094	9,766

[a] Variable costs for litter, electricity, tap water, cadaver and manure disposal, health care, hygiene, levies, catching hens, (un)loading hens and interest on laying hens per purchased hen per round (PHR^{-1}).
[b] General fixed costs for administration, insurances, memberships, company car, etc.
[c] Investments for cadaver cooling, fencing, vegetation and shelters in the outdoor run.

from the feed company to the farm. The assumed distance over land was 100 km for manure that was transported to Dutch arable farms and 450 km for manure that was transported to German arable farms.

For conventional concentrate ingredients, transport type (truck, ship, train) and distance were based on Mollenhorst (2005), whereas for organic feed ingredients transport type and distance were based on interviews with two organic feed companies (Table 2.2). Lime and sand were assumed to be transported 450 km over land from Germany and Belgium. Resource use and emissions related to transport over land and water were based on Ecoinvent (2007).

2.2.3. Economic performance

The economic performance of a farm is determined by three aspects: profitability, liquidity and solvability (Van Calker et al., 2005). Because these aspects are interrelated, and solvability and liquidity are indirectly determined by profitability, we compared the seven housing systems of laying hen husbandry for profitability. Profitability was measured by the indicator net farm income (NFI). NFI is the difference between total revenues and total costs, excluding costs of labour and own equity (Van den Tempel and Giesen, 1992). First, we calculated gross margin (GM) per laying hen per production round by subtracting variable costs per hen per production round from total revenues per hen per round. Second, we calculated GM per full time employee (FTE) per year, by correcting for round duration and for number of animals per FTE. Third, we calculated NFI per FTE per year by subtracting fixed costs per FTE per year from GM per FTE per year. Total revenues included revenues from eggs and slaughter hens. Variable costs included costs for concentrates and rearing hens and other costs, such as costs for energy, water and manure disposal. Interest on laying hens was considered to be a variable cost because it depends on the variable cost price of a rearing hen. Fixed costs included general costs, e.g. accounting, insurance, taxes, and costs for depreciation, maintenance and interest. Depreciation, maintenance and interest were calculated for investment costs of buildings and equipment, and structuring of the outdoor run. For land, only interest was calculated. Interest was calculated solely for foreign capital, which was assumed 50% of total capital.

Production data required for economic evaluation were similar to those used for ecological evaluation (Table 2.3). Additional economic data are listed in Table 5 (KWIN-V, 2007). The number of hens per FTE depended on the production system. The number of days the hen house was unoccupied between production rounds was 21 for loose housing systems and 17 for the battery cage system. General investment costs were assumed equal for each production system. Investments were highest for buildings and equipment. Investments for buildings and silos were higher for single-tiered than for multi-tiered systems, because hen density in single-tiered systems was lower. However, investments for equipment were lower for single tiered than for multi-tiered. Investments for land and remaining investments were highest for husbandry with an outdoor run, since more land per hen place is required and the outdoor run results in additional costs for fencing, vegetation and shelters. Interest, depreciation, and maintenance costs were calculated as a percentage of the investment, and assumed to be equal for all production systems. Depreciation was 3% on buildings, 7% on equipment in single-tiered husbandry, 6.5% on equipment in multi-tiered husbandry and battery cages, and 10% on other investment costs. Maintenance was 1% on buildings, 2% on housing equipment, 3% on egg collection equipment, and 5% on other investment costs. Interest was 2.5% on land and 4.2% on average invested capital in buildings and equipment.

2.3. Results

2.3.1. Ecological performance

In each paragraph of this section, we first report the range of ecological indicator scores for all egg production systems. Subsequently, the relative importance of substances or subsystems to an indicator score is discussed. Based on this information, actual differences in indicator scores among production systems are explained.

Global warming potential

Total global warming potential, expressed in g CO_2 equivalents per kg egg, was lowest for battery cage (2235), highest for free range (2740-2754) and intermediate for organic (2533-2547) and barn systems (2666-2685) (Table 2.6). Overall production systems, CO_2 emission contributed most to global warming potential (51-59%), whereas N_2O emission had the second highest contribution (38-45%). The contribution of CH_4 was marginal. The subsystems that contributed most to CO_2 emission were concentrate and litter production (28-32%) and transport (17-19%). Emission of CO_2 from concentrate and litter production resulted from energy use for field operations, drying of grain, production of artificial fertilizers and mining of lime. Emission of CO_2 from transport resulted mainly from transport of concentrate ingredients and manure. The subsystems that contributed most to N_2O emission were concentrate and litter production (11-22%) and laying hen husbandry (13-29%). Emission of N_2O from concentrate and litter production resulted from N fertilization, whereas emission of N_2O from laying hen husbandry mainly resulted from manure in hen house and manure storage facilities. Differences in global warming potential among egg production systems mainly resulted from differences in feed conversion (i.e. kg feed kg^{-1} egg), differences in fossil CO_2 emission and N_2O emission during crop cultivation, and differences in N_2O emission from hen husbandry. The battery cage had the lowest global warming potential per kg egg, mainly because N_2O emission from hen husbandry and feed conversion were lower compared with other systems. N_2O emission from battery cage husbandry was lowest because, due to low feed conversion, excretion of N was low. In addition, in battery cage husbandry manure in the hen house is dried intensively and removed weekly. Organic production had the highest feed conversion, but an intermediate global warming potential, because CO_2 and N_2O emission per kg concentrate ingredient were low compared with conventional crop production. Emission of fossil CO_2 during organic cultivation was lower because no artificial fertilizer, which requires fossil energy for production, and fewer field operations were used. Moreover, low manure application rates in organic cultivation resulted in lower emission of N_2O.

Energy Use

Total energy use, expressed in MJ per kg egg, was lower for organic (20.3-20.8 MJ) and battery cage systems (20.7), compared with free range (23.1-23.8) and barn systems (22.5-23.2) (Table 2.6). The subsystems concentrate and litter production (49-57%) and transport (32-38%) were the main contributors to energy use. Energy use from concentrate and litter production mainly resulted from energy use for field operations, drying of grain, production of artificial fertilizers and mining of lime. Energy use from transport mainly resulted from transport of feed ingredients and hen manure. Differences in energy use among egg production systems mainly resulted from differences in feed conversion and differences in EU during crop cultivation. The battery cage had a low energy use, because of a low feed conversion. Organic production had a higher feed conversion than the battery cage, but a similar energy use per kg egg because of low energy use during crop cultivation (no artificial fertilizer, few field operations).

Land occupation

Total land occupation, expressed in m^2 $year^{-1}$ per kg egg was lowest for the battery cage system (3.26), highest for organic systems (6.75-6.76), and intermediate for barn (3.75) and free range systems (4.07-4.08) (Table 2.6). The subsystem concentrate and litter production contributed 93-98%

Table 2.6 (a) Ecological indicator scores of different egg production systems, i.e. global warming potential (GWP), energy use (EU), land occupation (LO), fossil P use (FPU), acidification potential (AP), nitrogen deficit (ND), phosphorus deficit (PD), nitrogen surplus (NS) and phosphorus surplus (PS).

	GWP				EU	LO	FPU
(unit) [b]	(g CO_2 eq.[a] kg^{-1})				(MJ kg^{-1})	(m^2y kg^{-1})	(g P kg^{-1})
	CO_2	CH_4	N_2O	total	total	total	total
Concentrate and litter production							
Battery cage	725	25	490	1240	11.2	3.21	10.92
Barn S[c]	836	28	563	1428	12.9	3.69	12.56
Barn M[c]	836	28	563	1428	12.9	3.69	12.56
Free range S[c]	857	29	579	1465	13.2	3.78	12.86
Free range M[c]	857	29	579	1465	13.2	3.78	12.86
Organic S[c]	721	20	290	1032	10.3	6.43	2.63
Organic M[c]	721	20	290	1032	10.3	6.43	2.63
Hatching and rearing hen husbandry							
Battery cage	46	5	51	102	0.9	0.03	0.10
Barn S[c]	50	6	77	133	1.0	0.03	0.10
Barn M[c]	49	6	78	133	1.0	0.03	0.10
Free range S[c]	53	7	81	140	1.1	0.03	0.11
Free range M[c]	52	6	82	140	1.0	0.03	0.11
Organic S[c]	51	10	103	164	1.5	0.06	0.12
Organic M[c]	51	10	105	165	1.5	0.06	0.12

Laying hen husbandry							
Battery cage	141	37	296	474	1.9	0.00	-
Barn S[c]	55	61	470	587	0.8	0.01	-
Barn M[c]	56	49	504	608	0.8	0.00	-
Free range S[c]	57	61	480	597	0.8	0.24	-
Free range M[c]	57	50	518	625	0.8	0.23	-
Organic S[c]	71	86	695	852	1.0	0.26	-
Organic M[c]	84	70	749	902	1.2	0.26	-
Transport							
Battery cage	402	12	5	418	6.6	0.02	-
Barn S[c]	516	15	6	537	8.6	0.02	-
Barn M[c]	477	14	6	497	7.9	0.02	-
Free range S[c]	530	16	6	552	8.8	0.02	-
Free range M[c]	489	14	6	510	8.1	0.02	-
Organic S[c]	467	14	4	486	8.0	0.01	-
Organic M[c]	430	13	4	447	7.3	0.01	-
Total							
Battery cage	1315	78	842	2235	20.7	3.26	11.02
Barn S[c]	1457	111	1117	2685	23.2	3.75	12.66
Barn M[c]	1418	97	1151	2666	22.5	3.75	12.66
Free range S[c]	1496	113	1145	2754	23.8	4.08	12.97
Free range M[c]	1456	99	1185	2740	23.1	4.07	12.97
Organic S[c]	1311	130	1092	2533	20.8	6.76	2.75
Organic M[c]	1286	112	1148	2547	20.3	6.75	2.75

[a] eq. = equivalent [b] kg^{-1} = per kg egg produced [c] S = single-tiered M = multi-tiered

Table 2.6 (b) Ecological indicator scores of different egg production systems, i.e. global warming potential (GWP), energy use (EU), land occupation (LO), fossil P use (FPU), acidification potential (AP), nitrogen deficit (ND), phosphorus deficit (PD), nitrogen surplus (NS) and phosphorus surplus (PS).

	AP			ND	PD	NS	PS
(unit) [b]	(g SO_2 eq.[a] kg^{-1})			(g N kg^{-1})	(g P kg^{-1})	(g N kg^{-1})	(g P kg^{-1})
	NH_3	SO_x/NO_x	total	total	total	total	total
Concentrate and litter production							
Battery cage	10.2	3.6	13.8	0.3	0.2	17.4	6.7
Barn S[c]	11.7	4.2	15.9	0.4	0.2	20.0	7.7
Barn M[c]	11.7	4.2	15.9	0.4	0.2	20.0	7.7
Free range S[c]	12.0	4.3	16.3	0.4	0.2	20.5	7.9
Free range M[c]	12.0	4.3	16.3	0.4	0.2	20.5	7.9
Organic S[c]	10.1	3.7	13.7	5.7	2.0	1.2	0.0
Organic M[c]	10.1	3.7	13.7	5.7	2.0	1.2	0.0
Hatching and rearing hen husbandry							
Battery cage	1.1	0.4	1.5	-	-	-	0.1
Barn S[c]	5.9	0.4	6.3	-	-	-	0.1
Barn M[c]	2.5	0.5	3.0	-	-	-	0.1
Free range S[c]	6.2	0.5	6.7	-	-	-	0.1
Free range M[c]	2.7	0.5	3.2	-	-	-	0.1
Organic S[c]	8.0	0.5	8.5	-	-	-	0.1
Organic M[c]	3.5	0.6	4.1	-	-	-	0.1

Laying hen husbandry							
Battery cage	5.0	1.6	6.6	-	-	-	0.0
Barn S[c]	34.5	1.8	36.3	-	-	-	0.0
Barn M[c]	14.3	2.1	16.4	-	-	-	0.0
Free range S[c]	35.1	1.8	36.9	-	-	0.8	0.4
Free range M[c]	15.4	2.1	17.5	-	-	0.8	0.4
Organic S[c]	50.8	2.6	53.4	-	-	1.2	0.5
Organic M[c]	22.3	3.1	25.4	-	-	1.2	0.5
Transport							
Battery cage	-	1.1	1.1	-	-	-	-
Barn S[c]	-	5.0	5.0	-	-	-	-
Barn M[c]	-	4.7	4.7	-	-	-	-
Free range S[c]	-	5.1	5.1	-	-	-	-
Free range M[c]	-	4.8	4.8	-	-	-	-
Organic S[c]	-	5.2	5.2	-	-	-	-
Organic M[c]	-	4.9	4.9	-	-	-	-
Total							
Battery cage	16.3	6.7	23.0	0.3	0.2	17.4	6.7
Barn S[c]	52.1	11.4	63.5	0.4	0.2	20.0	7.7
Barn M[c]	28.5	11.4	40.0	0.4	0.2	20.0	7.7
Free range S[c]	53.4	11.7	65.0	0.4	0.2	21.3	8.3
Free range M[c]	30.1	11.8	41.8	0.4	0.2	21.3	8.3
Organic S[c]	68.9	12.0	80.8	5.7	2.0	2.4	0.7
Organic M[c]	35.9	12.2	48.1	5.7	2.0	2.4	0.7

[a] eq. = equivalent [b] kg^{-1} = per kg egg produced [c] S = single-tiered M = multi-tiered

to land occupation. Differences in land occupation among egg production systems mainly resulted from differences in feed conversion, and crop yield per ha. Land occupation of organic egg production was highest, because yield of the main concentrate ingredient organic wheat was low (2500 kg ha^{-1}) compared with yield of conventional wheat (6753-7567 kg ha^{-1}) and because feed conversion was highest of all systems.

Fossil P use

Total fossil P use, expressed in g P per kg egg, was lowest for organic systems (2.75), highest for free range (12.97) and barn systems (12.66), and intermediate for battery cage systems (11.02). The subsystem concentrate and litter production contributed 96–99% to fossil P use. Fossil P use during production of concentrates and litter resulted from use of artificial P fertilizer during production of conventional feed ingredients and use of lime (including $Ca(H_2PO_4)_2$) as a feed ingredient in concentrates of laying hens. The 2.63 g fossil P use for organic concentrate and litter production originated from use of lime in concentrates only. Differences in fossil P use among egg production systems resulted from differences in feed conversion and differences in use of artificial P fertilizer during crop production.

Acidification potential

Total acidification potential, expressed in g SO_2 equivalents per kg egg, was lowest for battery cage (23.0), highest for single-tiered loose housing systems (63.5 for barn, 65.0 for free range and 80.0 for organic) and intermediate for multi-tiered loose housing systems (40.0 for barn, 41.8 for free range and 48.1 for organic). For all production systems, NH_3 emission contributed most to acidification potential (71-85%) and resulted mainly from the subsystems laying hen husbandry (22-63%) and concentrate and litter production (12-44%). NH_3 emission from laying hen husbandry originated from manure in house and manure storage. Differences in NH_3 emission among production systems related to the subsystem laying hen husbandry resulted from differences in N excretion, differences in manure removal from the house and differences in manure drying techniques. Differences in NH_3 emission among production systems related to the subsystem concentrate and litter production resulted from differences in N fertilization. Overall, the battery cage had the lowest acidification potential, because feed conversion and N excretion were, lowest, and manure in the house was air dried and removed weekly. Multi-tiered housing systems had a lower acidification potential than single-tiered housing systems, because in multi-tiered houses manure was removed weekly, whereas in single-tiered houses manure remained in the house until the end of the production round.

N deficit and P deficit

For the organic systems, total N deficit was 5.7 g N per kg egg and total P deficit was 2.0 P per kg egg, whereas for the other systems total N and P deficit was negligible (0.3 to 0.4 for N deficit and 0.2 for P deficit). The only subsystem that contributed to N and P deficit was concentrate and litter production. The main cause for the occurrence of N and P deficit of organic egg production was a low amount of applied manure.

N surplus and P surplus

Total N and P surplus of conventional systems (i.e. 17.4-21.3 for NS and 6.7-8.3 for PS) was about ten times higher than total N and P surplus of organic systems (i.e. 2.4 for N and 0.7 for P surplus). The subsystem that contributed most to N and P surplus was concentrate and litter production. N and P surplus in the outdoor run (i.e. rearing and laying hen husbandry) was of minor importance. Differences in N and P surplus between organic and conventional production systems resulted from the difference in applied amount of NP fertilizer (i.e. artificial fertilizer and manure) during crop cultivation. Differences in N and P surplus among conventional production systems resulted from differences in feed conversion.

2.3.2. Economic performance

The GM per purchased rearing hen per round (PHR) was lowest for battery cage husbandry (2.16 € PHR^{-1}) and highest for organic husbandry (8.03-8.25 € PHR^{-1}) (Table 2.7). Differences in GM per PHR among production systems were most of all caused by differences in egg price (Table 2.5). When GM was expressed per FTE, on the other hand, GM was lowest for single-tiered organic husbandry (59,066 € FTE^{-1}) and highest for multi-tiered free range husbandry (134,971 € FTE^{-1}). This change in outcome was caused by differences in the number of laying hens per FTE for different types of laying hen husbandry (Table 2.5). For the same reason, GM per FTE was higher for multi-tiered than for single-tiered husbandry. Fixed costs were lowest for single-tiered organic husbandry (50,947 € FTE^{-1}) and highest for battery cage husbandry (122,633 € FTE^{-1}). Fixed costs also were higher for multi-tiered than for single-tiered laying hen husbandry. These differences were most of all explained by differences in investment costs for hen house equipment (Table 2.5). NFI was lowest for single-tiered barn husbandry (-17,744 € FTE^{-1} yr^{-1}) and highest for multi-tiered free range husbandry (32,550 € FTE^{-1} yr^{-1}). In general, multi-tiered husbandry resulted in a higher NFI than single-tiered husbandry. NFI of battery cage and barn husbandry was negative.

Table 2.7 Resulting economic indicators: revenues and variable costs per purchased hen per round (PHR^{-1}), gross margin, and fixed costs and net farm income per full time employee (FTE^{-1}) of battery cage (B), single (S) and multi-tiered (M) barn, single and multi-tiered free range and single and multi-tiered organic hen husbandry.

	(unit)	B	Barn		Free range		Organic	
			S	M	S	M	S	M
Revenues								
Eggs	(€ PHR^{-1})	15.21	17.17	17.17	19.03	19.03	29.81	29.81
Slaughter hens	(€ PHR^{-1})	0.19	0.2	0.2	0.19	0.19	0.27	0.27
Total revenues	(€ PHR^{-1})	15.4	17.37	17.37	19.22	19.22	30.08	30.08
Variable costs								
Concentrates	(€ PHR^{-1})	8.56	9.13	9.13	8.89	8.89	14.59	14.59
Rearing hens	(€ PHR^{-1})	3.1	3.5	3.5	3.6	3.6	6.02	6.02
Other [a]	(€ PHR^{-1})	1.58	1.51	1.51	1.6	1.59	1.22	1.44
Total variable costs	(€ PHR^{-1})	13.24	14.14	14.14	14.09	14.08	21.83	22.05
Gross margin	(€ PHR^{-1})	2.16	3.23	3.23	5.13	5.14	8.25	8.03
Gross margin	(€ FTE^{-1} y^{-1})	108,247	69,025	96,635	112,257	134,971	59,066	83,942
Fixed costs								
Depreciation	(€ FTE^{-1} y^{-1})	70,761	44,332	58,495	46,002	52,901	20,367	35,712
Maintenance	(€ FTE^{-1} y^{-1})	21,580	14,712	17,984	15,547	16,736	6,752	11,176
General cost	(€ FTE^{-1} y^{-1})	16,500	16,500	16,500	16,500	16,500	16,500	16,500
Interest	(€ FTE^{-1} y^{-1})	13,792	11,225	11,696	16,275	16,284	7,328	10,482
Total fixed costs	(€ FTE^{-1} y^{-1})	122,633	86,769	104,675	94,324	102,421	50,947	73,870
Net farm income	(€ FTE^{-1} y^{-1})	-14,386	-17,744	-8,040	17,933	32,550	8,119	10,072

[a] Costs for manure disposal, interest on laying hens, electricity, water, health care, hygiene, litter, levies, catching and (un)loading of hens, and cadaver disposal.

2.4. Discussion

2.4.1. Ecological evaluation

Only two other studies assessed ecological impact of an egg using a similar LCA approach (De Vries and De Boer, 2010): one for Dutch production systems (Mollenhorst et al., 2006) and one for UK systems (Williams et al., 2006). Our LCA results were lower for global warming potential, higher for energy use and more variable for land occupation and acidification potential compared with LCA results of Mollenhorst et al. (2006) and Williams et al. (2006). Lower global warming potential was explained by new insights into N_2O emission from crop cultivation (IPCC, 2006). Higher energy use was caused by inclusion of more processes and more process details for subsystems concentrate and litter production and laying hen husbandry. Larger variation in land occupation was caused by larger variation in feed conversion among hens in different housing systems, and differences in yields for organic and conventional concentrate ingredients. The larger variation in acidification potential was caused by a correction we made of NH_3 emissions from the hen house for N excretion, which varied among production systems, whereas Mollenhorst et al. (2006) and Williams et al. (2006) did not. Unlike Mollenhorst et al. (2006) and Williams et al. (2006) we assessed fossil P use and N and P deficit. We incorporated fossil P use because Smit et al. (2009) report that with the current predicted rise in fossil P use, fossil P will be depleted within the next 75 years. One of the major causes for a rise in fossil P use is an expected rise in the global consumption of animal food products per capita. N and P deficit were included as an ecological indicator, because they may lead to soil degradation, which is a sustainability issue especially for organic production.

Differences in LCA results among production systems can be explained mainly by differences in feed conversion, in parameters that determine ecological impact per kg feed ingredient (e.g., crop yield per ha; number field operations, type and amount of fertilizer), in drying of grain, in transport of concentrates and manure, in type of hen house and in N excretion per hen per year.

An increase in feed conversion increased the ecological impact per kg egg. Feed conversion of production systems averaged 2.3, and varied from 2.0 in battery cage system to 2.6 in organic production. Feed conversion, therefore, is one of the important steering parameters to reduce ecological impact of egg production. At this moment, feed conversion is higher in loose housing systems compared with the battery cage system. A higher feed conversion in loose housing systems is partly inherent to loose hen housing, but differences in feed conversion among farms show that there is potential for improvement, especially for organic production. The standard deviation of feed conversion among 20 interviewed organic egg farms, for example, was 0.3. An improved feed conversion in organic production may be realized by changes in, for example, feed composition, in farm management, in genetic merit of the hen, in metabolic energy demand of the hen, in occurrence of feather pecking or diseases, and in the percentage of damaged eggs (Van Knegsel and Van Krimpen, 2008).

Besides improving feed conversion, ecological impact of egg production can be reduced by lowering the ecological impact from cultivation of concentrate ingredients and litter by: increasing crop yield per hectare, optimizing amount and type of field operations, and by optimizing fertilization related to crop yield.

Organic concentrate ingredients, especially wheat, had a two times higher land occupation compared with conventional concentrate ingredients. Moreover, organic concentrate and litter production resulted in depletion of nutrients (i.e. high N and P deficit). The main reason for this high land occupation, N and P deficit was the low yield per ha for organic crops caused by a lack of manure application. This effect was most apparent for organic wheat, originating from Ukraine (Table 2.3). Intensification of field operation and increasing NP fertilization using manure would decrease land occupation and N and P deficit, but increase energy use, global warming potential and acidification potential through emission of fossil CO_2 and emission of NH_3 and N_2O from manure application. For each concentrate ingredient, therefore, land occupation, N deficit, and P deficit must be optimized against acidification potential, global warming potential and N and P surplus. According to latest insights of IPCC (2006), N fixation does not contribute to direct N_2O emission. Use of legumes in hen feed, therefore, should be explored as a mitigation strategy in organic egg production.

Transport of concentrates and laying hen manure is a major contributor to global warming potential and energy use. Producing feed and eggs in the same region, therefore, can reduce the amount of transport and related ecological impacts. The current Dutch arable area cannot sustain the feed requirements of the current Dutch livestock population (CBS, 2010). Moreover, optimized production of feed ingredients in Southern or Eastern European countries might result in lower ecological impacts (including emission related to transport) compared with Northern European circumstances, due to favourable climatic and soil conditions. These arguments highlight the importance of optimizing the ecological impact of production and transport of concentrates from a life cycle perspective. Similarly, crop fertilization should be optimized from a life cycle perspective because application of manure and artificial fertilizer application show different ecological impacts. Use of manure instead of artificial fertilizer for crop fertilization, for example, reduces fossil P use, whereas it also implies storage of manure resulting in emission of NH_3, N_2O and CH_4. Moreover, emission of NH_3 from manure application is higher compared with emission of NH_3 emission from fertilizer application.

The combination of housing type and N excretion of hens had a major effect on acidification potential (emission of NH_3) and global warming potential (emission of N_2O). Manure removal, as practiced in multi-tiered housing, and manure drying, as practiced in battery cage housing, appeared a good option to reduce NH_3 and N_2O emission from hen husbandry. N excretion of hens can be reduced by lowering the amount of N in concentrates, especially in the feed of loose housed hens. Loose housed hens may need less amino acids than battery caged hens, since they produce less eggs, but they may need more carbohydrates for maintenance (Van Knegsel and Van Krimpen, 2008). Reduction of N excretion of organic hens, however, is hampered by the fact that use of synthetic amino acids (e.g. lysine and methionine) is not allowed since they are produced by genetically modified organisms. The use of mined lime and $Ca(H_2PO_4)_2$ should be minimized and energy use during processes should be optimized. The ecological benefits of replacing mined lime by shell grit should be explored.

Uncertainty of LCA results might affect ranking of egg production systems or relative importance of mitigation options. Uncertainty of our LCA estimates mainly depends on methodological choices and data quality. In order to assess global warming potential, we used equivalence factors for a 100-year time horizon (i.e. 1 for CO_2, 25 for CH_4 and 298 for N_2O). In case we would have used equivalence factors for a 500-year time horizon (i.e. 1 for CO_2, 7.6 for CH_4 and 153 for N_2O) the relative importance of CO_2 compared to N_2O would increase, whereas the importance of CH_4 would remain negligible. Use of a 500-year time horizon equivalence factors reduced absolute values of global warming potential per kg of egg, but did not affect the ranking of egg production systems.

We did not account for CO_2 emissions resulting from changes in land use, such as deforestation, related to production of feed ingredients. These emissions were not accounted for, because data and method to calculate these emissions are limited and uncertain (IPCC, 2006). In our research, CO_2 emissions from deforestation is especially relevant for production of soy bean expeller. The concentrates contained only 12-17% soy bean expeller. Accounting for deforestation would increase global warming potential per kg egg, and enlarge the effect of feed conversion on differences in global warming potential among production systems.

Uncertainty related to data quality is determined among others by methods used to estimate emissions. As emissions of CO_2, NH_3 and N_2O are of relatively major importance in final LCA results, uncertainty related to their estimations are most relevant. Emission of CO_2 is mostly related to combustion of fossil fuels and can be quantified rather accurately (Ecoinvent, 2007). Emission of NH_3 and N_2O from, for example, N application during crop production depends on type of fertilizer used, application technique used and climatic and soil conditions, and, therefore, shows a large geographical variation. Incorporation of this geographical variation in current LCA is hampered, however, by data availability. Emission of NH_3 and N_2O in hen husbandry highly depends on type of housing, type of manure storage and N excretion. Current knowledge on level and variation of NH_3 emission, especially from organic production systems, and N_2O emission from hen house and manure storage is limited, and requires additional research.

2.4.2. Economic evaluation

NFI per FTE differed considerably among housing systems. Most important determinants affecting these differences were price of eggs, price of feed, number of hens per FTE and investment costs for equipment, which was also found by Mollenhorst et al. (2006).

An increase in egg price across systems will increase NFI of systems with a high egg productivity per hen and a higher number of FTE per farm (i.e. battery cage and multi-tiered systems) relatively more. Similarly, an increase in feed price will reduce NFI most for systems with a high number of FTE per farm and a high feed conversion. The effect of an increase in number of hens per FTE will be highest for organic and free range systems, and will be higher for multi-tiered compared with single-tiered systems. For battery cage systems NFI will decrease as the number of hens per FTE will increase further, due to the high additional investment costs for buildings and equipment. Increasing the number of hens per FTE or the number of FTE per farm in organic production might be a feasible strategy to increase NFI per farm.

2.5. Conclusion

A ban on battery cages is expected to increase global warming potential, land occupation and acidification potential per kg of egg, whereas the effect on energy use, fossil P use, N and P deficit and N and P surplus depends on relative importance of different loose housing systems. Of all loose housing systems, organic systems had lowest global warming potential, energy use, fossil P use and N and P surplus, whereas land occupation, N and P deficit was lowest for barn systems. Acidification potential was lowest for multi-tiered barn system due to manure drying. Ecological impact of loose housing systems can be improved by lowering feed conversion; lowering ecological impact per kg feed ingredient (e.g. increase crop yield per ha; reduce field operations, choice of fertilizer and reduce fertilization), by efficient processing and transport, by balancing NP in feed with nutritional requirements of hens and by drying of manure (i.e. multi-tiered housing). Free range systems had highest NFI per FTE, followed by the multi-tiered organic system. NFI of battery cage and barn husbandry was negative. In case differences among egg and cost prices of different systems do not change after a ban on the battery cage, multi-tiered free range and organic systems are economically most favourable.

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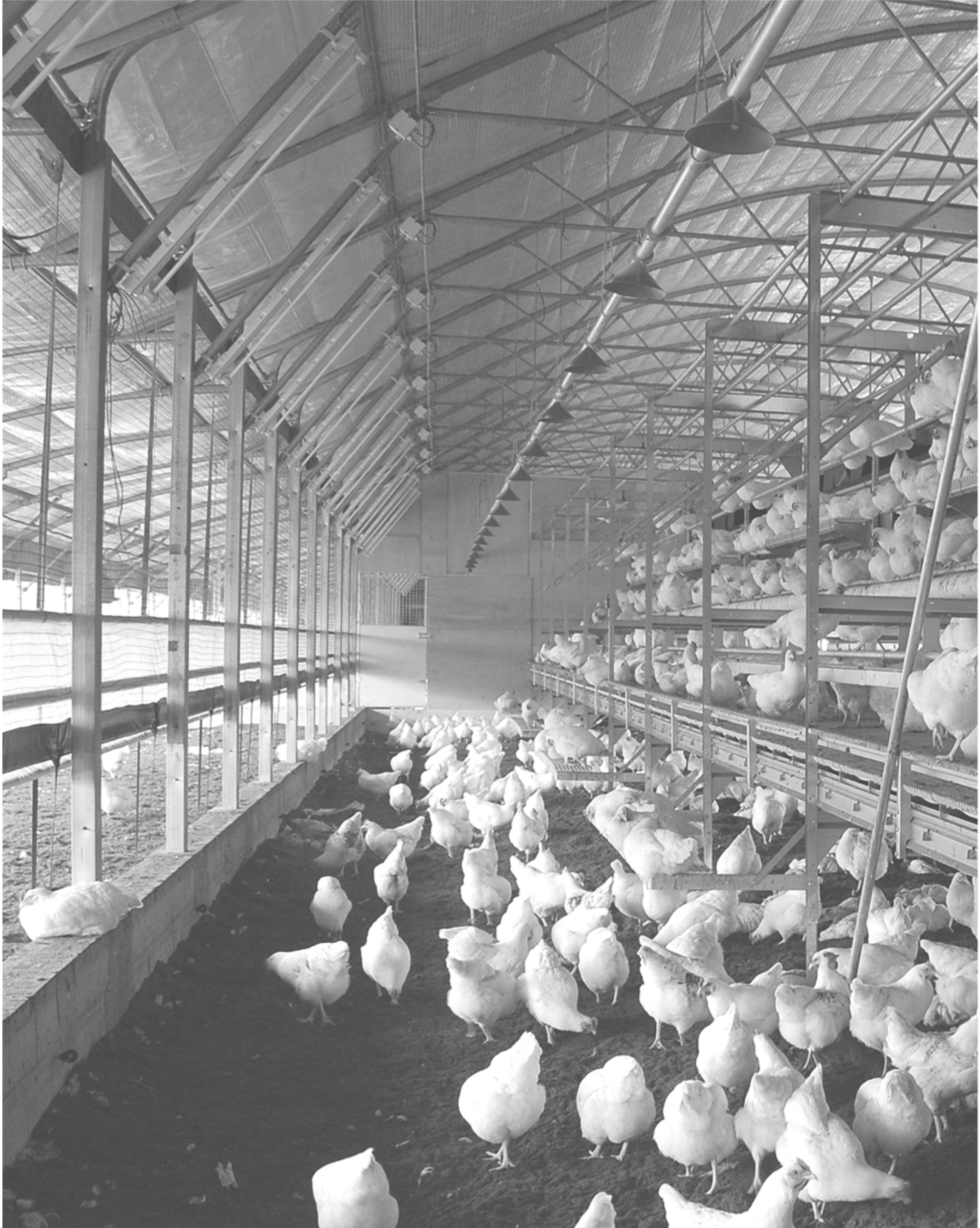

Chapter 3

Emissions of ammonia, nitrous oxide, and methane from aviaries with organic laying hen husbandry

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Abstract

The first objective of this study was to measure the year round emissions of ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) from three commercial aviary systems with organic laying hen husbandry. The second was to determine the effect on NH_3, N_2O and CH_4 emissions of varying removal interval when using manure belts. Emissions were computed from the ventilation rate, calculated with the carbon dioxide (CO_2) mass balance method, and gas concentrations of NH_3, N_2O, and CH_4 inside and outside the hen house. Mean emission per hen for NH_3 was 410 mg d^{-1}, for N_2O was 3.12 mg d^{-1}, and for CH_4 was 81.7 mg d^{-1}. Mean predicted emission per hen for NH_3 on the first day after manure removal was 298 mg d^{-1}, and increased by 5.47% d^{-1}. The presence of manure on the belt did not affect emissions of N_2O and CH_4. Emission of NH_3 from aviary systems with organic laying hen husbandry was in the same range as emission of NH_3 from aviary systems with non-organic laying hen husbandry. Using organic laying hen husbandry in aviary systems instead of single-tiered systems has the potential to reduce emissions of NH_3, N_2O, and CH_4; further reductions might be realised by changes in litter management.

Nomenclature

V	ventilation rate (m^3 h^{-1})
$CO_{2\ production}$	CO_2 produced by a hen present in the hen house and by the manure produced by the hen (m^3 d^{-1})
$[CO_2]_{inside}$	concentration of CO_2 of inside air (m^3 m^{-3})
$[CO_2]_{outside}$	concentration of CO_2 of outside air (m^3 m^{-3})
D	fixed effect of presence of manure on the belt
e	residual effect
f	random effect of farm
H	linear effect of hours since manure removal
i	farm
j	two-day-measurement period within farm
k	measurement day within two-day-measurement period
m_{body}	mean body mass (kg hen^{-1})
m_{egg}	mean egg mass (kg d^{-1} hen^{-1})
w	random effect of two-day-measurement period
Y_{NH3}	emission of NH_3 (mg hen^{-1} d^{-1})
$Y_{N2O/CH4}$	emission of N_2O or CH_4 (mg hen^{-1} d^{-1})
β	constant for effect of hours since manure removal
Φ_{tot}	total heat dissipation in floor houses (kW h^{-1} hen^{-1})
μ	mean

Abbreviations

BAT	best available techniques
DM	dry-matter
REML	restricted maximum likelihood

3.1. Introduction

The livestock sector has a major impact on the environment because of its emissions to air, water, and soil (Steinfeld et al., 2006). Emissions of NH_3, N_2O, and CH_4 from animal houses contribute to this impact. Volatilisation of NH_3 causes acidification, eutrophication, and loss of biodiversity through uncontrolled and excessive ammonium (NH_4^+) deposition in natural ecosystems (Lekkerkerk, et al., 1995). Greenhouse gases N_2O and CH_4 reduce heat loss from the planet, resulting in global warming (IPCC, 2001). Emissions of NH_3 and N_2O from manure reduce the nitrogen (N) content of manure. This decreased N content of manure negatively affects the capacity of manure to fertilize crops, which is especially relevant for organic farming where the use of artificial fertilization is prohibited.

European Union legislation states that farms with more than 40,000 laying hens should implement the best available techniques (BAT), such as housing system, to reduce NH_3 emission (EC, 2008). From 2013 onwards, Dutch farms have to apply BAT; an exception is made, however, for organic farming (VROM, 2005). European Union legislation, however, states that organic farming should avoid environmental pollution and that organic livestock production is fundamental to provide nutrients for organic crop production (EC, 1999b).

Loose hen housing is typical for organic laying hen husbandry. In 2007, 85% of the hens in Dutch organic laying hen husbandry were housed in a single-tiered system and 15% were housed in an aviary system (Dekker et al., 2009). In a single-tiered system, hens live on one level, partly with litter and partly with a tiered surface above a manure pit. In an aviary system, hens live on multiple levels, with a litter surface on the lowest level and tiered wire floors above manure belts on higher levels; see, e.g. VROM (2010). Dekker et al. (2011b) concluded that emissions of NH_3, N_2O, and CH_4 along the entire organic egg-production chain mainly occur on laying hen farms; (for a single-tiered system, 74% of total NH_3, 64% of total N_2O and 66% of total CH_4). They also concluded that a promising option to reduce these emissions is to house hens in an aviary system instead of a single-tiered system.

In non-organic laying hen husbandry, i.e. loose hen housing without an outdoor run, emissions per hen per year (y) of NH_3, N_2O, and CH_4 are higher from a single-tiered system (402 g y^{-1} for NH_3, 15.8 g y^{-1} for N_2O, and 39.8 g y^{-1} for CH_4) than from an aviary system (129 g y^{-1} for NH_3, 11.2 g y^{-1} for N_2O, and 7.3 g y^{-1} for CH_4) (Mosquera et al., 2009; Winkel et al., 2009b). In a single-tiered system manure drops onto the litter or into the manure pit. This manure remains in the house until the end of the production cycle. In an aviary system, however, 70%-90% of manure drops onto the manure belt. This manure is allowed to dry and removed frequently. A high dry-matter (DM) content of this manure reduces biological breakdown of uric acid, proteins, and organic matter, and consequently reduces emissions of NH_3, N_2O, and CH_4 (Groot Koerkamp, 1994).

However, in an aviary system with organic laying hen husbandry emissions of NH_3, N_2O, and CH_4, may differ from emissions in an aviary system with non-organic laying hen husbandry, because the housing system and production variables between these husbandry systems differ (Table 3.1). In organic laying hen husbandry hen density is 6 hens m^{-2} and in non-organic laying hen husbandry hen density is 9 hens m^{-2} (EC, 1999a). In contrast to non-organic laying hen husbandry, hens in organic laying hen husbandry have access to an outdoor run (EC, 1991; EC 1999b). Hens in organic laying hen husbandry have higher feed conversion (kg feed kg^{-1} egg), higher N excretion, higher mortality rate, lower egg production and shorter production cycle than in non-organic laying hen husbandry (Dekker et al., 2011). Emissions of NH_3, N_2O, and CH_4 from hen houses with organic laying hen husbandry have not yet been measured in practise. The first objective of this study, therefore, was to measure the year round emissions of NH_3, N_2O, and CH_4 from three commercial aviary systems with organic laying hen husbandry. The second was to determine the effect of interval of removal of manure from manure belts on the measured emissions of NH_3, N_2O, and CH_4.

3.2. Materials and methods

3.2.1. Experimental layout

The experiment was executed on three farms with organic laying hen husbandry located in the Dutch province of Gelderland. Each farm had an aviary system placed inside the hen house (Fig. 3.1), an outdoor run, a winter garden (i.e. a covered litter surface located between the hen house and the outdoor run), organic certification for more than four years, and a hen house that was used for at least one production cycle. Measurements on farms 1 and 2 were executed in one compartment of a hen house with 3000 places for hens, whilst on farm 3, because air exchange between these compartments was possible, two compartments with in total 6000 places were measured. Mean hen mass during the measurements were 1.85 kg on farm 1, 1.91 kg on farm 2, and 1.75 kg on farm 3.

Measurements were taken between October 2008 and February 2010, four times on each farm, and equally spread over the year. A measurement lasted two days. On both days temperature; relative humidity;

gas concentrations of NH_3, N_2O, CH_4, and CO_2 of outside and inside air were measured for 24 h. The number of hens in the outdoor run was also estimated. Measurements of day 1 were started the day before the farmer planned to remove manure from the manure belts. Before the start of the measurements on day 2 manure was removed from the belts. On day 1, faeces, litter, and manure samples were collected. On day 2, the farmer completed a questionnaire regarding production variables and management characteristics.

Table 3.1 Production variables of non-organic and organic loose laying hen husbandry in the Netherlands (Dekker et al., 2011b).

Production variables	(unit)	Non-organic	Organic
Density of house	(hen m^{-2})	9	6
Density of outdoor run	(hen m^{-2})	-	0.25
Production cycle duration	(d)	406	398
Feed consumption	(kg hen^{-1})[a]	45.3	44.9
Egg production	(kg hen^{-1})[a]	19.9	17.3
Nitrogen excretion	(kg hen^{-1})[a]	0.747	0.962
Mortality	(%)	9	13

[a] kg per hen place.

From these measurements the mean hourly, daily and yearly emissions of NH_3, N_2O, and CH_4 and the effect of interval of removal of manure from manure belts on the measured emissions of NH_3, N_2O, and CH_4 were calculated. Diurnal patterns of emissions of NH_3, N_2O, and CH_4 were calculated and manure composition, temperature, and relative humidity were measured to understand better the observed emissions.

3.2.2. Housing system and management

Manure belts were situated under wire-mesh tiered floors, to allow faeces to fall through (Fig. 3.1). Air from inside the building was blown over the belts to dry the manure. Manure was removed from manure belts and stored in a separated manure-storage facility. The interval between manure removals was typically between 3 and 7 days and varied among farms, because of the management preferences of the farmer.

The hen houses on farms 1 and 2 were mechanically ventilated with exhaust fans at the ridge of the roof (Fig. 3.1) and outside air entered the hen house on one side directly through valves whilst on the other side it entered via the winter garden through pop holes and inlet valves. Farm 3 was naturally ventilated. Outside air entered the hen house through the upwind side wall and was exhausted through the downwind side wall (Fig. 3.1). On each farm, the temperature of the hen house was set to 20 ºC and was controlled automatically by the ventilation rate of the exhaust fans (farms 1 and 2) or by changing the opening size of the transparent impermeable curtains in the side walls (farm 3). Ventilation rate depended on ventilation management (manual control of inlet valves and pop holes), outside temperature, wind speed, and wind direction in relation to orientation of the hen house.

Table 3.2 Available surface per hen, mean (SD) of the daily management schedule and production variables on Farms 1, 2 and 3.

	(unit)	Farm 1	Farm 2	Farm 3
Surface	(m^2 hen^{-1})			
Hen-house litter		0.089	0.093	0.099
Winter-garden litter		0.057	0.035	0.025
Manure belt		0.074	0.064	0.040
Daily management schedule	(h d^{-1})			
Lights on		15.4 (1.11)	16.1 (0.25)	16.8 (0.50)
Outdoor run open		11.1 (1.88)	9.00 (2.20)	8.25 (0.41)
Production variables				
Feed-intake	(g hen^{-1} d^{-1})	125 (12.5)	124 (19.0)	122 (13.3)
Nitrogen-intake	(g hen^{-1} d^{-1})	3.33 (0.45)	3.78 (0.71)	3.67 (0.54)
Concentrate in ration	(%)	62.5 (2.7)	79.2 (12.7)	73.2 (5.3)
CCM[a] in ration	(%)	7.5 (8.0)	-	6.0 (7.3)
Wheat in ration	(%)	30.0 (8.5)	20.8 (13.1)	20.8 (5.2)
Egg mass	(g hen^{-1} d^{-1})	52.1 (2.95)	52.0 (5.45)	52.3 (5.40)
Hens in experiment	(nr)	2743 (201)	2948 (104)	6040 (111)
Hens inside[b]	(%)	95.3 (3.79)	98.9 (1.09)	95.4 (1.08)

[a] CCM = corn-cob maize
[b] Mean daily

On each farm, hens had free access to water and feed. Feed was a mixture of organic concentrate and corn-cob maize (Table 3.2). On farms 1 and 2, wheat was added to the feed. Perches, feed chains, and water nipples were located above the manure belts (Fig. 3.1). On farm 3, feed was offered in round feeders above the litter floor and spread loose on the litter floor with mechanical feed casters (Fig. 3.1). In the winter garden of farm 1, water was offered in circular drinkers, and grass silage bales were placed loose on the litter. In the winter garden of farm 3, corn-cob maize was spread loose on the litter daily. Bedding material, (sawdust on farms 1 and 2 and flax straw on farm 3) was applied at the start of the production cycle. Farms 1 and 3 also applied bedding material in the winter garden.

From about noon until shortly after sunset, the pop holes or the lowest part of curtains between the hen house, the winter garden and the outdoor run were opened to give the hens access to the winter garden and the outdoor run. Daily management and production variables of the three farms are given in Table 3.2.

3.2.3. Measurements

Gas concentrations of NH_3, N_2O, CH_4, and CO_2

Gas concentrations were measured at two sampling points per farm; one for outside air and one for inside air. On farms 1 and 2, the sampling point for outside air was underneath the gutter of the winter garden and the sampling point for inside air was in the ventilation shaft (Fig. 3.1). Four tubes were used to sample air on each of two sampling points. On farm 3, the sampling point for outside air was 3 m South-West (prevailing wind direction) of the hen house and the sampling point for inside air was in the centre of the hen house. On farm 3 each of two sampling points consisted of one tube with six openings placed in series equally spaced over the length of the hen house. Each of the six openings had a critical orifice of 1 l min^{-1}. The air flow from each of the two sampling points was split in four samples.

Air samples were sucked through tubes and samplers by pumps (Model 607CD32, Thomas Industries Inc., Wabasha, MN, USA). The flow rate of air samples was controlled by the critical orifices. Four air samples per sampling point were used: two to obtain a duplicate of the mean daily concentration of NH_3; one to obtain mean daily concentrations of N_2O, CH_4, and CO_2; and one to obtain mean hourly concentrations of NH_3, N_2O, CH_4, and CO_2.

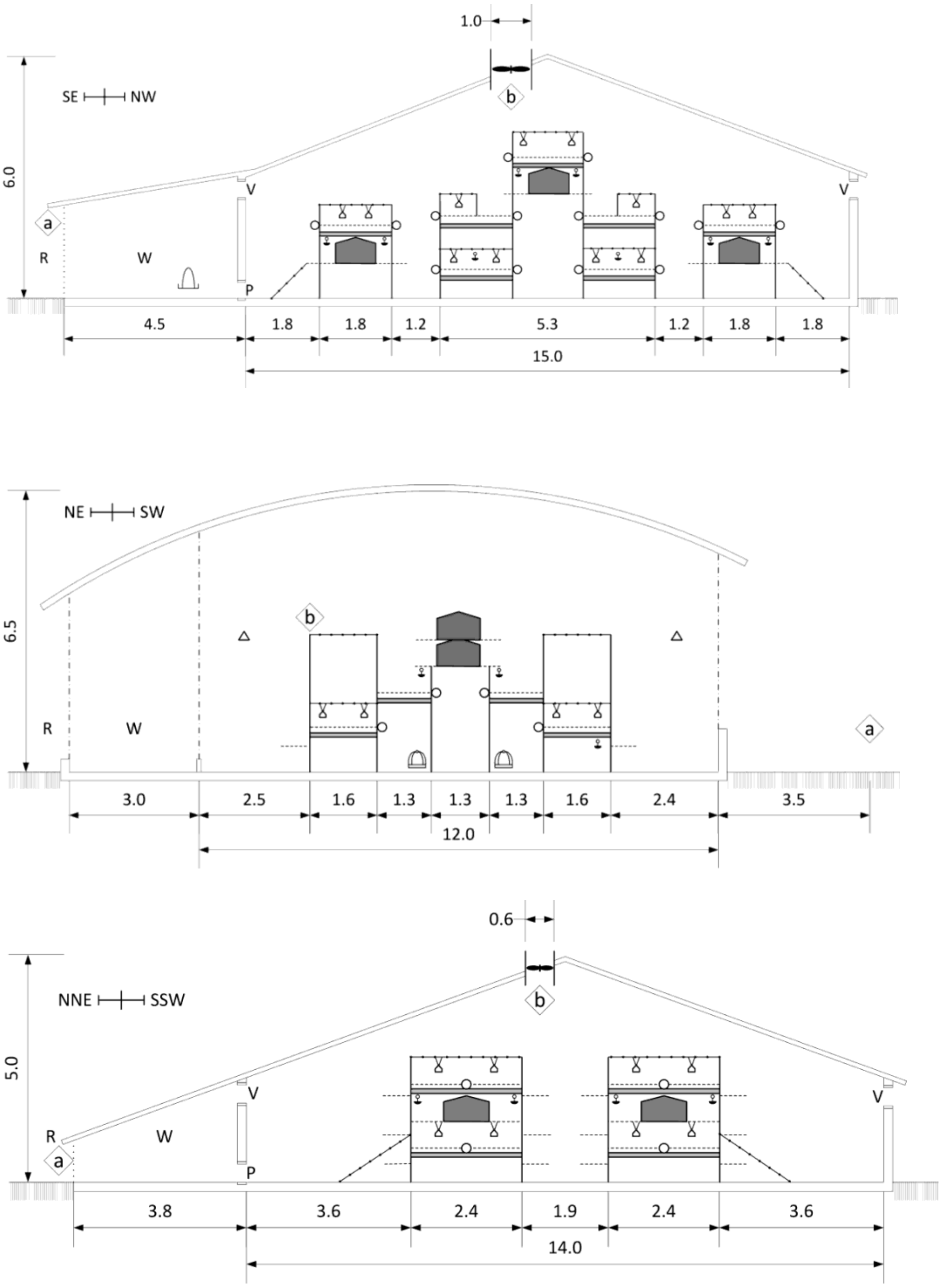
Mean daily inside and outside concentrations of NH_3 were determined using the wet chemical method. The air sample was continuously sucked through two serially placed impingers at an air-flow rate of 1.0 l min^{-1}. The NH_3 in the air sample was trapped in 0.1 l nitric acid (HNO_3) solution (0.05 mol l^{-1}) placed in each of the two impingers. Concentration of NH_4^+-N in the HNO_3 solution of the first two impingers was determined with a photo spectrometer. Total NH_3 mass in an impinger was determined by multiplying the concentration of NH_4^+-N with the mass of the HNO_3 solution and with the molecular weight of NH_3. To obtain mean daily concentration of NH_3 in the air, total NH_3 mass in the first two impingers was summed and the total was divided by the total sampled volume of air. Before and after each one day period of measurement, the air-flow rate was verified using an air-flow meter (Defender 510-m, Bios Int. Corp, NJ, USA). The mean difference between the duplicate NH_3 concentrations was 3.2%.

To determine mean daily inside and outside concentrations of N_2O, CH_4, and CO_2, the air was sampled with the lung method (Le et al., 2005). A 40-l Teflon bag was placed in an airtight barrel. Before the measurement, the bag was flushed with clean air and then sucked empty. At the start of measurement, the bag was connected to a sampling tube. During measurement, air was sucked out of the barrel at an air-flow rate of 0.02 l min^{-1}, causing negative pressure in the barrel and, consequently, causing the bag to be filled with the air sample. Air in the bag was analysed for concentrations of N_2O, CH_4, and CO_2 in duplicate with a gas chromatograph (GC 8000, Interscience, Nom la Bretêche, France/Carlo Erba Instruments, Rodano, Milan, Italy). Maximum acceptable differences between duplicates were 5.6% for N_2O, 2.8% for CH_4, and 2.8% for CO_2.

Mean hourly inside concentrations of NH_3, N_2O, CH_4, and CO_2 were calculated from 5-min measurements with a multi-gas monitor (Innova, Type 1312, Innova AirTech Instruments, Ballerup, Denmark). According to the technical specification of the instrument, the accuracy of the gas measurement was ± 0.1 ppm for NH_3, ± 6 ppm for CO_2, ± 0.2 ppm for CH_4 and ± 0.02-0.2 ppm for N_2O. The multi-gas monitor was regularly calibrated. Hourly inside concentrations were corrected for daily outside concentrations and multiplied with hourly ventilation rates to obtain hourly emissions of NH_3, N_2O, and CH_4. Hourly emissions of a measurement day were divided by mean daily emission to obtain a relative diurnal emission pattern. Daily inside and outside concentrations measured with the wet chemical or lung methods were multiplied with daily ventilation rates to obtain absolute mean daily emissions of NH_3, N_2O, and CH_4.

Temperature and relative humidity

Two combined sensors, located close to the two air sampling points, continuously measured outside and inside temperature and relative humidity on each farm (Rotronic I-100; ROTRONIC Instrument Corp., Huntington, WV, USA) with a precision of ± 1.0 ºC and ± 2.0%. Mean hourly data were stored in a data logger (CR10, Campbell Scientific Inc., Logan, IL, USA), and were used to compute mean daily inside and outside temperature and relative humidity.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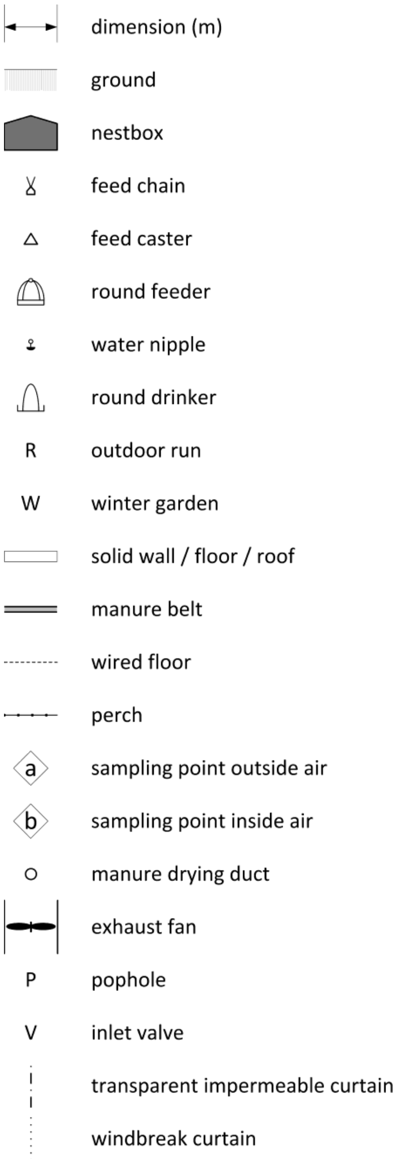

Figure 3.1 Cross sections of the hen house on farms 1, 2 and 3.

Composition of manure and feed samples

Freshly excreted faeces were sampled on day 1 of every two day measurement. About 25 fresh manure droppings were collected every day from a clean plastic plate placed on the wired surface above one of the manure belts.

On day 1 of every two-day measurement three samples were taken from the three surfaces of the aviary system (Table 3.2): the litter surface in the hen house (five to 62 subsamples cut from randomly allocated locations), the litter surface in the winter garden (sub-sampling method equal to litter in the hen house), and the manure belt surface (five subsamples from the manure storage directly after removal

on farm 1, and two subsamples from two random allocated locations on belts for farms 2 and 3).

Manure and faeces samples were stored in closed containers at 5 ºC until analysis. Manure and faeces samples were analysed for content for: DM by gravimetric determination after drying for one day at a temperature of 105 ºC, total N and NH_3-N by distillation and total phosphorus (P) by distillation and photometric determination.

Hens in the outdoor run

The number of hens in the outdoor run was counted visually during day time. The number of hens in three specific plots in three zones was interpolated to calculate mean hourly and daily percentage of hens outside (Dekker et al., 2010). This percentage was used to correct the number of hens present in the hen house and their CO_2 production.

3.2.4. Analysis of gaseous emissions

Emission rates of NH_3, N_2O, and CH_4 were calculated by multiplying the absolute difference between outside and inside concentrations of NH_3, N_2O, and CH_4 with the ventilation rate. Emissions per hen (hens present in the hen house on the measurement day) were expressed in mg d^{-1} and emissions per hen place (initial number of hens housed, period the hen house was empty excluded) were expressed in g y^{-1}. Ventilation rate was calculated with the CO_2 mass balance method (Pedersen et al., 2008) by dividing the calculated production of CO_2 by the difference between outside and inside concentrations of CO_2:

$$V = (CO_{2\,production} / 24) / [CO_2]_{inside} - [CO_2]_{outside} \quad (1)$$

Where V is ventilation rate (m^3 h^{-1}), $CO_{2\ production}$ is CO_2 produced by a hen present in the hen house and by the manure produced by the hen (m^3 d^{-1}), $[CO_2]_{inside}$ is concentration of CO_2 of inside air (m^3 m^{-3}), $[CO_2]_{outside}$ is concentration of CO_2 of outside air (m^3 m^{-3}).

Production of CO_2 was calculated from heat dissipation, as described by the calculation rule for laying hens on floors as defined by Pedersen and Sällvik (2002), section II:

$$\Phi_{tot} = 6.8 * m^{0.75}_{body} + 25 * m_{egg} \qquad (2)$$

Where Φ_{tot} is total heat dissipation in floor houses (kW h^{-1} hen^{-1}), m_{body} is mean body mass (kg hen^{-1}), m_{egg} is mean egg mass (kg d^{-1} hen^{-1}).

Production of CO_2 in the hen house was calculated by multiplying total heat dissipation per laying hen with the conversion variable at house level for laying hens of 0.18 m^3 CO_2 kW^{-1}, as recommended by Pedersen et al. (2008). Production of CO_2 was corrected for mean daily percentage of hens outside. To account for the daily pattern of production of CO_2, we assumed that production of CO_2 during the period lights were off was 80% of the mean daily production and we compensated for it during periods the lights were on (von Wachenfelt et al., 2001).

3.2.5. Statistical analysis

The restricted maximum likelihood (REML) was used, in combination with a Wald test, to estimate variance components for emissions of NH_3, N_2O, and CH_4. Simple linear regressions showed that the variables temperature, relative humidity and manure composition did not explain emissions computed; these variables, therefore, were not included as variance components in REML.

Emission of NH_3 model (Equation 3) was analysed using a logscale in the model to obtain a normal distribution.

$$log\ Y_{NH3ijk} = \mu + \beta * H_{ijk} + f_i + f_i * w_j + f_i * w_j * e_k \qquad (3)$$

Where Y_{NH3ijk} is emission of NH_3 (mg hen^{-1} d^{-1}) on farm i, at two-day-measurement period j, and day k; μ is mean; β is the constant for effect of hours since manure removal; H_{ijk} linear effect of hours since manure removal on farm i, at two-day measurement period j, and day k; f_i is the random effect of farm i, $f \sim N(0; \sigma^2_F)$; w_j is the random effect of two-day measurement period j within farm, $w \sim N(0; \sigma^2_w)$; e_k is the random residual effect on day k within two-day-measurement period and farm, e N $(0; \sigma^2_E)$.

Table 3.3 Temperature (T) and relative humidity (RH) outside and inside the hen house; ventilation rate; concentrations of ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) outside and inside the hen house; and emissions of NH_3, CH_4, and N_2O on Farms 1, 2 and 3. Mean, SD, minima (min) and maxima (max) are based on means of a two-day period.

		Farm 1				Farm 2				Farm 3			
		mean	SD	min	max	mean	SD	min	max	mean	SD	min	max
Climatic conditions													
T (°C)	Outside	10.6	10.1	-2.54	22.2	8.92	7.55	2.03	21.0	12.3	6.02	4.74	19.5
	Inside	22.6	1.96	19.7	25.5	19.9	5.43	12.1	27.5	20.9	1.96	18.1	23.3
RH (%)	Outside	79.3	14.4	54.7	99.5	83.2	11.4	67.6	100	88.0	8.20	76.3	98.2
	Inside	59.5	12.1	45.1	79.4	58.4	8.01	49.0	72.3	70.7	3.95	64.9	76.4
Ventilation rate ($m^3\ hen^{-1}\ h^{-1}$)		2.71	1.42	1.14	4.31	2.31	0.68	1.30	3.19	2.22	0.79	1.22	3.30
Concentrations													
NH_3 (ppm)	Outside	0.30	0.12	0.13	0.47	0.55	0.37	0.20	1.30	0.08	0.03	0.05	0.14
	Inside	12.7	9.45	1.85	25.0	14.6	7.66	4.98	27.0	15.5	13.0	1.90	37.9
N_2O (ppm)	Outside	0.22	0.04	0.15	0.26	0.24	0.03	0.21	0.28	0.26	0.02	0.24	0.29
	Inside	0.24	0.07	0.14	0.35	0.26	0.03	0.20	0.31	0.31	0.06	0.24	0.39
CH_4 (ppm)	Outside	3.13	0.99	2.19	4.55	2.65	0.42	2.20	3.43	2.66	0.64	2.16	3.65
	Inside	8.80	5.81	3.56	18.60	3.76	0.89	2.50	5.13	4.22[a]	1.35	3.02	6.34
CO_2 (ppm)	Outside	510	90	439	670	483	49	433	583	463	36	432	507
	Inside	1,545	686	904	2,582	1,510	413	1,152	2,249	1,503	429	1,006	2,124

Emissions												
NH_3 (mg hen^{-1} d^{-1})	353	141	116	589	463	170	182	676	414	241	81	734
N_2O (mg hen^{-1} d^{-1})	3.74	5.56	-1.94	14.6	2.18	3.13	-1.07	7.93	3.87	4.99	-1.59	11.3
CH_4 (mg hen^{-1} d^{-1})	151	105	62	387	34	12	10	45	54[a]	16	38	82

[a] During one of four two-day periods on Farm 3, CH_4 concentration measurements failed

In the emission models of N_2O and CH_4 (no log transformation; Eq. (4)) the linear effect of hours was replaced since manure removal was a fixed effect for the presence or lack of manure on the belt.

$$Y_{N2O/CH4ijk} = \mu + D_{ijk} + f_i + f_i * w_j + f_i * w_j * e_k \qquad (4)$$

Where $Y_{N2O/CH4ijk}$ is emission of N_2O or CH_4 (mg hen^{-1} d^{-1}) on farm i, at two-day-measurement period j, and day k; μ is mean; D_{ijk} is the fixed effect of presence of manure on the belt on farm i, at two-day-measurement period j, and day k; f_i is the random effect of farm i, $f \sim N(0; \sigma^2_F)$; w_i is the random effect of two-day-measurement period j within farm, $w \sim N(0; \sigma^2_W)$; e_k is the random residual effect on day k within the two-day measurement period and farm, $e \sim N(0; \sigma^2_E)$.

3.3. Results and discussion

3.3.1. Mean daily temperature, relative humidity, and ventilation rate

The two-day minimum and maximum outside temperatures (-2.54 ºC to 22.2 ºC) and relative humidity (54.7% to 100%) (Table 3.3) differed considerably. This difference was caused by seasonal fluctuations. Over all farms, the mean outside temperatures (10.6 ºC) and relative humidity (83.5%) were close to the mean yearly temperature (9.7 ºC) and relative humidity (83%) for the Netherlands (Heijboer and Nellestijn, 2002). The mean inside temperature per farm ranged around the set point temperature of 20 ºC from 19.9 ºC on farm 2 to 22.6 ºC on farm 1 (Table 3.3). The mean inside relative humidity varied from 58.4% on farm 2 to 70.7% on farm 3. Over all the farms the mean inside temperature was 21.1 ºC, and relative humidity was 62.9% which was very close to the temperature and relative humidity found in aviaries with non-organic laying hen husbandry (Winkel et al., 2009b) (temperature: 21.0 ºC, relative humidity: 63.4%) (Groot Koerkamp & Elzing, 1996) (temperature: 21.1 ºC, relative humidity: 67.7%). Mean outside and inside temperature and relative humidity on farms 1, 2 and 3 were in the same range (Table 3.3) and, therefore, were not expected to cause differences in emissions among farms. The mean ventilation rates on farms 1, 2 and 3 ranged from 2.22 to 2.71 m^3 hen^{-1} h^{-1} (Table 3.3) and were lower than ventilation rates measured in aviary systems with non-organic laying hen husbandry by Winkel et al. (2009b) (about 3 m^3 hen^{-1} h^{-1}).

Table 3.4 Mean and (SD) of content for dry matter (DM), total nitrogen (N), ammonia nitrogen (TAN), phosphorus (P), for faeces, hen-house litter, winter-garden litter, and belt manure.

Content	Farm 1		Farm 2		Farm 3		All farms	
DM (g kg^{-1})								
Faeces	250	(37)	235	(31)	230	(31)	238	(32)
Hen-house litter	835	(55)	716	(123)	774	(22)	775	(87)
Winter-garden litter	774	(178)	658	(252)	834	(28)	755	(179)
Belt manure	498	(70)	375	(49)	382	(79)	419	(85)
Total N (g kg^{-1} DM)								
Faeces	62.8	(13.7)	61.9	(8.1)	55.3	(12.9)	59.8	(11.5)
Hen-house litter	28.0	(8.4)	35.2	(4.4)	31.4	(6.6)	31.5	(6.8)
Winter-garden litter	22.8	(13.9)	35.0	(4.4)	18.3	(6.6)	25.4	(11.1)
Belt manure	36.4	(12.4)	50.6	(12.9)	51.9	(12.0)	46.3	(13.4)
TAN (% of N content)								
Faeces	68.5	(2.6)	63.2	(2.8)	64.4	(2.5)	65.6	(3.3)
Hen-house litter	11.2	(3.2)	14.8	(9.1)	17.5	(9.3)	14.5	(7.5)
Winter-garden litter	16.9	(7.4)	13.9	(8.5)	13.3	(4.3)	14.7	(6.5)
Belt manure	31.7	(2.2)	26.5	(8.8)	49.4	(12.8)	35.9	(13.1)
P (g kg^{-1} DM)								
Faeces	11.5	(3.1)	15.3	(1.3)	13.8	(2.9)	13.4	(2.9)
Hen-house litter	9.8	(2.3)	15.7	(1.2)	10.3	(0.6)	11.9	(3.1)
Winter-garden litter	6.3	(3.1)	15.3	(2.7)	4.9	(0.6)	8.9	(5.3)
Belt manure	12.1	(2.6)	15.9	(2.0)	15.4	(2.4)	14.4	(2.7)

3.3.2. Gas concentrations of NH_3, N_2O, CH_4, and CO_2

Inside concentrations of NH_3 (min 1.85 ppm to max 37.9 ppm) and CO_2 (min 904 ppm to max 2582 ppm) were always higher than outside concentrations of NH_3 (min 0.05 ppm to max 1.30 ppm) and CO_2 (min 432 ppm to max 670 ppm) (Table 3.3). Mean concentrations of NH_3 per farm (12.7-15.5 ppm) measured in this study were within the range of concentrations of NH_3 (1-16 ppm) measured by Groot Koerkamp and Bleijenberg (1998). Mean concentrations of CO_2 were comparable among farms, reflecting similar ventilation rates. Inside concentrations of N_2O (min 0.14 ppm to max 0.39 ppm) and CH_4 (min 2.50 ppm to max 18.60 ppm) were low and not always higher than outside concentrations of N_2O (min 0.15 ppm to max 0.29 ppm) and CH_4 (min 2.16 ppm to max 4.55 ppm). Differences between inside and outside concentrations of N_2O resulted, on some days, in negative emissions (i.e. an influx) of N_2O being measured (Table 3.3). This could have been caused by measurement errors, because concentration levels of N_2O in this study were close to their limit of detection.

3.3.3. Composition of litter and manure

Over all farms the mean DM content was low for faeces (238 g kg^{-1}), intermediate for manure from the belt (419 g kg^{-1}), and high for litter from the winter garden (775 g kg^{-1}) and the hen house (755 g kg^{-1}) (Table 3.4). Over all the farms the mean total N content and percentage of NH_3-N in total N, was high for faeces (59.8 g kg^{-1} DM and 65.6%), intermediate for manure from the belt (46.3 g kg^{-1} DM and 35.9%) and low for litter from the hen house (31.5 g kg^{-1} DM and 14.5%) and the winter garden (25.4 g kg^{-1} DM and 14.7%). Mean DM content, and total N, and percentage of NH_3-N in total N of faeces in aviary systems for organic laying hen husbandry was comparable to mean DM content (225 g kg^{-1}), and total N (66.7 g kg^{-1} DM), and percentage of NH_3-N in total N (67.5%) of faeces from aviary systems with non-organic laying hen husbandry (Groot Koerkamp, 1994). Mean DM content of belt manure was comparable with DM content of belt manure at removal after one week (500-700 g kg^{-1}) (Groot Koerkamp, 1994). Mean DM content of litter from the house and winter garden in organic laying hen husbandry was in accordance with the range of DM content of litter (600-800 g kg^{-1}) reported by Groot Koerkamp (1994).

Litter manure is a mixture of faeces and bedding material. The P content of bedding material is lower than the P content of faeces. The P content of litter, therefore, must be lower than the P content of faeces and belt manure. The total P content of all manure types was similar on farm 2, indicating that little bedding material was added (Table 3.4). On farms 1 and 3, however, P content of the hen house and the winter-garden litter was lower than for faeces and belt manure, indicating that larger amounts of bedding material were added than on farm 2.

To calculate the percentage of N added as faeces that was emitted from manure, the percentage of bedding material and faeces present in the litter of hen house or winter garden in this study (in terms of DM, see Table 3.5) was calculated. This calculation was based on the N and P content of the faeces samples and N and P content of bedding material and litter (Olayinka and Adebayo, 1989; Tushar et al., 2010). It was assumed that 100% of P in belt manure originated from faeces. Based on these percentages, the N added as faeces to belt manure, the litter from the hen house and the winter garden was calculated. The percentage of N added as faeces that was emitted from the manure was calculated by subtracting the N present in the manure samples from the N added as faeces and dividing by the N added as faeces. Table 3.5 shows that less faeces was added to litter from the winter garden

(51%) than to litter from the hen house (89%), but the percentage varied between farms. The percentage of N emitted from N added as faeces was highest for litter from the hen house (38%), intermediate for the litter from the winter garden (25%) and lowest for the belt manure (20%). Collecting faeces on manure belts might therefore be the most effective way of reducing N emission from faeces in aviary systems for organic laying hens. Adding more bedding material to the litter may be an effective strategy to reduce N emission from faeces in the litter, because by adding bedding material DM contents lowered, which slows down the emission of NH_3.

Table 3.5 Nitrogen (N) and phosphorus (P) content of bedding material, added percentage of total dry matter (DM) in faeces, and percentage of total DM in bedding material and emitted N percentage from N added as faeces to hen-house litter, winter-garden litter and hen-house belt-manure (SE).

	Farm 1	Farm 2	Farm 3	All farms
Content of bedding material (g kg^{-1} DM)				
N content	1.1[a]	1.1[a]	12[b]	-
P content	2.3[a]	2.3[a]	1.7[c]	-
DM added as faeces to (%)				
Hen-house litter	94 (26)	102 (5)	75 (10)	89 (10)
Winter-garden litter	41 (15)	102 (11)	23 (1)	51 (12)
Hen-house belt-manure	100 (-)	100 (-)	100 (-)	100 (-)
N emitted from N added as faeces (%)				
Hen-house litter	46 (9)	42 (3)	27 (8)	38 (5)
Winter-garden litter	2 (21)	43 (2)	34 (21)	25 (11)
Hen-house belt-manure	41 (9)	15 (19)	3 (12)	20 (8)

[a] Bedding material = sawdust (Olayinka and Adebayo 1989).
[b] Bedding material = flax straw. (Tushar et al., 2010).
[c] Bedding material = flax straw. The P content of flax was not available from literature, so we used P content of bean straw (CVB, 2008).

3.3.4. Emissions of NH_3, N_2O, and CH_4

Based on the values in Table 3.3, mean emissions per hen were calculated as 410 mg d^{-1} for NH_3 (SE 38.0), 3.12 mg d^{-1} for N_2O (SE 0.94), and 81.7 mg d^{-1} for CH_4 (SE 17.5). Mean emissions per hen place were 144 g y^{-1} for NH_3 (SE 13.5), 1.11 g y^{-1} for N_2O (SE 0.33), and 27.4 g y^{-1} for CH_4 (SE 5.19). Per livestock unit (1 livestock unit equals 500 kg live animal weight) emissions were 39.2 kg y^{-1} for NH_3, 0.30 kg y^{-1} for N_2O, and 7.5 kg y^{-1} for CH_4. Mean emission per hen of NH_3 was 458 mg d^{-1} (SE 55.4) on the first measurement day and 362 mg d^{-1} (SE 50.6) on the second measurement day. Emission of CH_4 was very high during day 2 of the first two-day-measurement period on farm 1.

Mean emission per hen place of NH_3 from aviaries with organic laying hen husbandry in this study (144 g y^{-1}, SE 13.5) was comparable with mean emission per hen place of NH_3 from aviary systems with non-organic laying hen husbandry (134 g y^{-1}) (Winkel et al., 2009b). Mean emissions per hen place of NH_3 in these studies were higher than the range of emissions of NH_3 for existing aviary systems (26-94 g y^{-1}) in the Netherlands VROM (2010), but lower than found in Norway for aviary systems: 272 g y^{-1} (corrected for inoccupation) (Nimmermark et al., 2009). Emissions per hen place of NH_3 from single-tiered systems with non-organic laying hen husbandry ranged in the Netherlands from 328 g y^{-1} (VROM, 2010) to 419 g y^{-1} (Mosquera et al., 2009). In the former Norwegian study it was 722 g y^{-1} (corrected for inoccupation). These emissions were considerably higher than emissions of NH_3 from the aviaries with organic laying hen husbandry in this study.

Mean emission per hen place of N_2O from aviaries with organic laying hen husbandry measured in this research was lower (1.11 g y^{-1}, SE 0.33) than mean emission per hen place of N_2O from aviary systems with non-organic laying hen husbandry (11.2 g y^{-1}) (Winkel et al., 2009b) and lower than mean emission per hen place of N_2O from single-tiered systems with non-organic laying hen husbandry (15.8 g y^{-1}) (Mosquera et al., 2009). Fabbri et al., (2007), however, could not detect emissions of N_2O in a deep-pit battery cage or a ventilated-belt battery cage. These differences may be explained by the differences between the inside and outside concentrations of N_2O which were near to zero in this and other studies (Fabbri et al., 2007; Winkel et al., 2009b). A small increase in concentration of inside N_2O therefore increases emissions of N_2O significantly.

Mean emission per hen place of CH_4 from aviary systems with organic laying hen husbandry in this study (27.4 g y^{-1}, SE 5.19) was the same as that from aviary systems with non-organic laying hen husbandry (27.5 g y^{-1}) (Winkel et al., 2009b). Mean emission per hen place of CH_4 from non-organic laying hen husbandry was higher for single-tiered housing systems (39.8 g y^{-1}) (Mosquera et al., 2009) than for aviary systems. Fabbri et al. (2007), measured high emissions per hen place of CH_4 for a ventilated-belt battery cage of 80 g y^{-1} compared with this study. For a deep-pit battery cage of 30 g y^{-1}, however, their measurements of emissions of CH_4 were comparable to this study. The difference between these battery cage systems could be attributed to the lower DM content of manure in the ventilated-belt battery cage (344 g kg^{-1}) than in the deep-pit battery cage (609 g kg^{-1}).

To calculate emissions, mean daily gas concentrations were multiplied with mean daily ventilation rates. This could underestimate the emission rate. Estelles, et al. (2010) investigated the magnitude of error committed when determining the mean daily ammonia emission from an animal house, based on 24-h averaged ammonia concentration and air-flow, in relation to semi-continuous measurements (e.g. every hour). In this study it was shown that the average systematic deviation between these methods was only 1.5%.

Diurnal patterns of emissions of NH_3 and N_2O relative to mean daily emissions were similar, whereas emission of CH_4 showed an inverted pattern (Fig. 3.2). When lights in the hen house were off, and the outdoor run was closed (between 21:00 and 3:00), emissions of NH_3 and N_2O were low, but emission of CH_4 was high. When lights in the hen house were on, but the outdoor run was closed (between 3:00 and 11:00), emissions of NH_3 and N_2O increased to a maximum at 11:00 h and emission of CH_4 decreased from a maximum at 4:00 to a minimum around 11:00. After the outdoor run was opened (from 11:00 to 21:00), emissions of NH_3 and N_2O stabilised at an intermediate value, whereas emission of CH_4 remained at a minimum level. The diurnal patterns showed that emissions of NH_3 and N_2O increased when hens were active and the emission of CH_4 increased when hens were inactive. High emissions of N_2O during the active period might be explained by hens scratching in the litter and the increased production of faeces on the litter. High emissions of CH_4 during the inactive period might be explained by anaerobic conditions in the litter caused by absence of foraging.

The diurnal pattern of the mean two-day relative emissions of NH_3 before manure removal resembled the pattern of that after manure removal (Fig. 3.3). The mean relative emission of NH_3 on the day before manure removal, however, was 19% higher than on the day after manure removal.

3.3.5. NH_3, N_2O and CH_4 emission model

The mean estimated values and SE for the fixed variables and variance components of the emission models of log NH_3, N_2O, and CH_4 are presented in Table 3.6. A Wald test showed that there was a significant positive linear effect of hours since manure removal on log emission of NH_3 ($\beta = 2.28$; 10^{-3} $P < 0.001$). Based on the value of β and 24 h d^{-1}, the relative daily increase of the emission of NH_3 after removal of belt manure was 5.47%. This daily increase resulted in a predicted mean emission of NH_3 if manure was removed after; one day of 298 mg NH_3 hen^{-1} d^{-1} (mean residence time of manure on the belts of 12.5 h); three days of 316 mg NH_3 hen^{-1} d^{-1} (60.5 h) and seven days of 354 mg NH_3 hen^{-1} d^{-1} (156.5 h). It should be noted, however, that emissions from the manure storage facility do not increase, because manure on the belt might have a lower DM content if the drying period on the manure belt is shortened.

For emissions of N_2O (D = 1.65; P = 0.17) and CH_4 (D = 15.75; P = 0.44), however, there was no significant effect of presence of manure on the belt. Emission of N_2O and CH_4 was not reduced by removal of manure from the belts. Apparently, emissions of N_2O and CH_4 are related predominantly to the amount and composition of the litter. This may also explain the relatively high variation in N_2O and CH_4 emissions between farms. Low emissions of N_2O and CH_4 in aviary systems with organic (this study) compared with non-organic laying hen husbandry, therefore, might result from differences in amount of litter, amount of litter surface, or litter conditions.

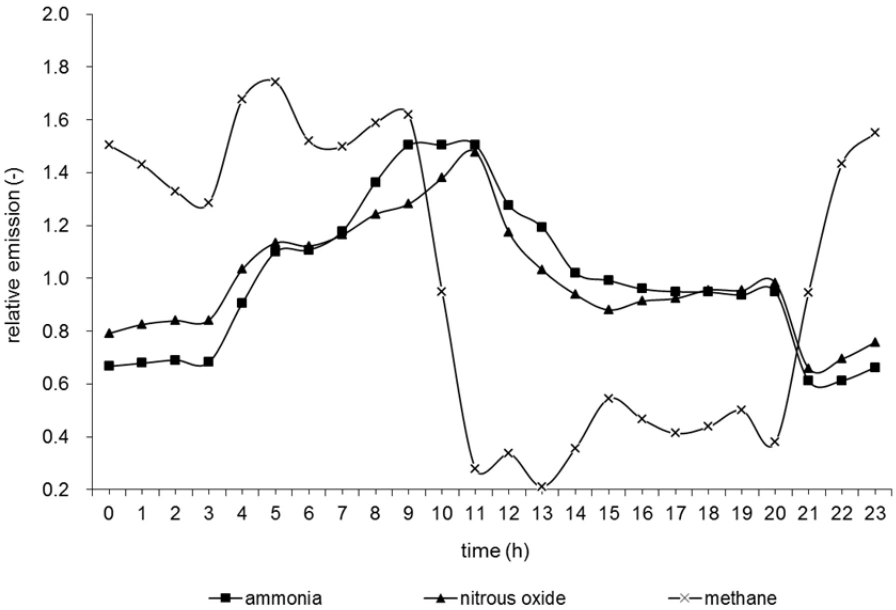

Fig 3.2 Example (Farm 1, two-day period 4, day 1) of the diurnal relative emission patterns of ammonia, nitrous oxide, and methane. Emissions are presented relative to mean emission of this day.

Further reductions of emissions of NH_3, N_2O, and CH_4 from aviaries with organic laying hen husbandry should be found in management of the litter, because most of the emissions of NH_3, N_2O, and CH_4 appear to originate from the litter. Reductions can be realised in various ways, including removing litter regularly, or increasing the DM content of the litter by adding bedding material.

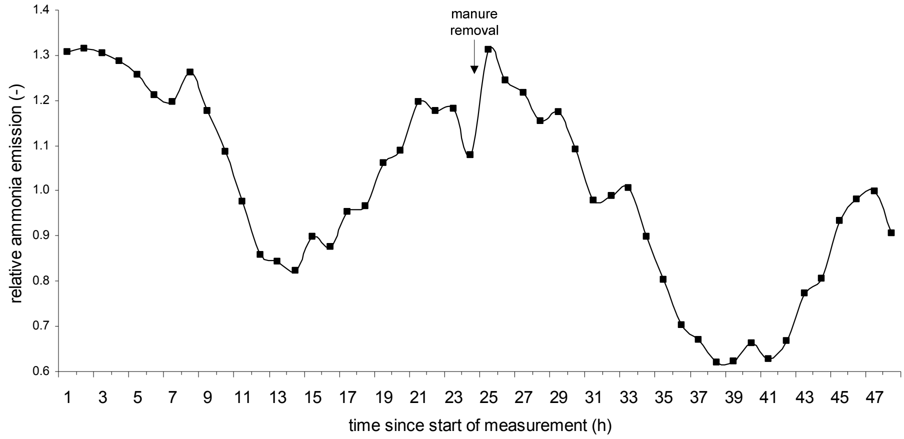

Figure 3.3 Mean (n=9) hourly relative emission pattern of NH_3 over time since the start of measurement. Mean hourly emissions of NH_3 are relative to mean two-day emission of NH_3.

Table 3.6 Mean estimate (SE) of the fixed variables (μ, β/D_{ijk}) and variance components (σ^2_f, σ^2_w, σ^2_e) of the emission models of log ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4).

	log NH_3		N_2O		CH_4	
μ	5.67	(0.173)	2.29	(1.33)	72.1	(38.17)
β/D_{ijk} [a]	$2.28*10^{-3}$	$(4.07*10^{-4})$	1.65	(1.13)	15.75	(19.75)
σ^2_f	0.00	(bound)	0.00	(bound)	3,104	(4,069)
σ^2_w	0.333	(0.146)	13.63	(7.61)	2,452	(1,823)
σ^2_e	$1.81*10^{-2}$	$(7.70*10^{-3})$	7.62	(3.25)	2,145	(959)

[a] β for log NH_3 model; D_{ijk} for N_2O and CH_4 model.

3.4. Conclusion

For aviary systems, with organic laying, the hen husbandry emissions of NH_3 and CH_4 were similar to those in non-organic laying hen husbandry. Emissions of N_2O were lower than seen in non-organic laying hen husbandry. The daily removal of belt manure reduced emissions of NH_3 from the hen house, whereas the presence of manure on the belt did not affect emissions of N_2O and CH_4. Housing organic laying hen husbandry in aviary systems instead of single-tiered systems has potential to reduce emissions of NH_3, N_2O, and CH_4. Further reduction in emissions of NH_3,

N_2O, and CH_4 from aviaries with organic laying hen husbandry could be realised mainly by changes in litter management.

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Chapter 4

Total loss and distribution of nitrogen and phosphorus in the outdoor run of laying hens

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Abstract

The objective of this study was to determine the level and variation of the total mass, and load of nitrogen (N) and phosphorus (P) excreted into the outdoor run of organic laying hen farms. Three farms with an aviary system and an outdoor run were selected for this study. Four measurements, one per season, were executed on each farm. Mean content of N and P of a manure dropping was 14.0 g N kg^{-1} (SD 1.75) and 3.12 g P kg^{-1} (SD 0.49), mean mass of a dropping was 6.36 g (SD 0.67) and mean dry matter content of a dropping was 238 g kg^{-1} (SD 32). Mean rate of excretion in the outdoor run was 2.99 droppings per hen per hour. Mean percentage of hens outside during the time the outdoor run could be accessed was lowest on farm 1 (1.7%), highest on farm 2 (13.0%), and mediate on farm 3 (7.1%). On all farms an exponential decrease of the number of hens and of the load of N and P with increasing distance from the hen house was found. In this study load of N exceeded the fertilization standard (of 170 kg ha^{-1} y^{-1}) in the region 0 to 19 m distance from the hen house on farm 1, 0 to 146 m on farm 2 and 0 to 52 m on farm 3. It is concluded that the husbandry system should be redesigned to solve the problem of overloading, unwanted losses of N and P to the environment and loss of N and P from the organic production cycle.

Nomenclature	
β_0	intercept constant
β_1	effect of distance
C_e	content of nitrogen or phosphorus of eggs
C_f	content of nitrogen or phosphorus of feed
C_h	content of nitrogen or phosphorus of manure on farm *h*
D	shortest distance from the centre of a plot to the curtain of the winter garden
E_{hk}	excretion of nitrogen or phosphorus (g hen^{-1} d^{-1}) on farm *h*, during measurement period *k* on that farm
$E(Y_{hijk})$	expected mean number of hens counted on farm *h*, in zone *i*, in plot *j*, during measurement *k*
f_h	random effect of farm *h*.
H_h	mean number of manure droppings excreted per hen per hour in the outdoor run on farm *h*
L_{hd}	load of nitrogen or phosphorus in the outdoor run on farm *h* at distance *d*
M_e	produced egg mass
M_f	feed intake
M_h	mass of a single manure dropping on farm *h*
m_k	random effect of measurement *k*
p_j	random effect of plot *j*
Y_{hd}	hen density on farm *h* at distance *d*
t_h	time period the outdoor run is accessible on farm *h*
γ_{0h}	fixed effect of farm *h*
γ_{1h}	fixed effect of farm *h* on distance
Abbreviations	
CCM	corn cob maize
DM	dry matter

4.1. Introduction

In organic production laying hens should have access to an outdoor run (EC, 1991; EC, 1999b). The outdoor run offers hens a natural environment which stimulates exploration, running, flying, foraging, sunbathing, and dust bathing behaviour, and reduces cannibalism and feather pecking (Knierim, 2006). In a natural ecosystem, the level of nitrogen (N) and phosphorus (P) in the soil is more or less balanced, because animals remove N and P by feeding on the vegetation and return most of this N and P in faeces and urine. In organic laying hen husbandry, however, excretion of N and P in the outdoor run is generally far exceeding the uptake by vegetation (Aarnink et al., 2006). Especially in organic farming reduction of loss of N and P from the production cycle is important, because the use of artificial fertilizers is prohibited (EC, 1991).

Total loss of N and P excreted into the outdoor run depends on the amount and composition of manure deposited, on the distribution of manure and on the uptake of these nutrients by vegetation. The amount of manure deposited in the outdoor run depends on the number of hens outside and time periods hens have access to the outdoor run. Content of N and P of manure is determined by feed composition and N and P use by the hens for egg production and growth. Distribution of manure will depend mainly on the distribution of hens in the outdoor run. Vegetation growth, especially in parts of the outdoor run with a high hen density, is very limited in practice, because vegetation is destructed by intensive foraging (Bubier and Bradshaw, 1998). Aarnink et al. (2006) showed that locally high loads of N and P (i.e. mass of N and P excreted per m^2 in the outdoor run) may occur, because hens tend to stay close to the hen house (Hegelund et al, 2005; Zeltner and Hirt, 2003). In a previous study we interviewed 20 Dutch organic laying hen farmers to obtain a quantified overview of organic laying hen husbandry in the Netherlands. Results from this study show that manure droppings are not removed from the outdoor run by the farmers and, therefore, N and P accumulate in the soil and will eventually be lost to the environment. These losses contribute to aquatic and terrestrial eutrophication, acidification and global warming (Steinfeld et al., 2006).

Load of N and P is defined as the concentration of nutrients excreted in a specific time period and location of the outdoor run (kg m^{-2} h^{-1}). Total mass of N and P excreted into the outdoor run is defined as the total amount of nutrients excreted in the complete outdoor run or a specific larger section of the outdoor run (kg d^{-1}). Measurement of total mass of N and P excreted into the outdoor run, and load of N and P by collection of manure droppings is unreliable, because: manure is trampled, manure is mixed with soil, dissolved N and P in manure leach into the soil, N may become volatile gas and objects placed on the surface to avoid contact of manure with soil affects distribution of the hens and, therefore, distribution of manure excretion (Grigor et al., 1995; Zeltner and Hirt, 2008). Measurement of the total loss of N and P from the outdoor run to deep soil layers, ground water, surface water and the air is labour intensive, technically complex and expensive when reliable results are required.

Total mass and load of N and P excreted into the outdoor run, however, can indirectly be determined by measuring: content of N and P of manure; mass of the freshly excreted manure dropping; rate of production of droppings by hens in the outdoor run; and total number and distribution of hens in the outdoor run. Total mass and load of N and P excreted into the outdoor run should be measured year round on several commercial farms for several flocks to obtain a realistic estimation under commercial circumstances, because of dependency on factors such as: diet (Elwinger et al., 2008); flock size (Hegelund et al., 2005); age (Hegelund et al., 2005; Mirabito and Lubac, 2001); genotype (Elwinger et al., 2008); rearing management (Bestman and Wagenaar, 2003; Grigor et al., 1995; Mirabito and Lubac, 2001); weather and climate (Elwinger et al., 2008; Hegelund et al., 2005); time period per day the outdoor run is accessible (Aarnink et al., 2006) and day rhythm of the hens (Bubier and Bradshaw, 1998; Hegelund et al., 2005; Zeltner and Hirt, 2008); layout of the outdoor run and presence of natural or artificial objects (Harlander-Matauschek et al., 2006; Zeltner and Hirt, 2003). Although some of the mentioned factors have been quantified in specific situations, a year round indirect determination of total mass and load of N and P excreted into the outdoor run on several commercial flocks and farms is missing.

The objective of this study, therefore, was to determine level and variation of load of N and P in the outdoor run and the total mass of N and P excreted into the outdoor run. We realised this by the former mentioned method of indirect determination on three commercial farms with organic laying hen husbandry. Results were compared with the total excretion of N and P determined by a mass balance of the three farms.

4.2. Materials and methods

4.2.1. Experimental layout

Three organic laying hen farms located in the Dutch province of Gelderland were chosen to execute the experiment. Each farm had: a hen house with an aviary system, a winter garden (i.e. an indoor litter surface located between hen house and outdoor run) and an outdoor run; an organic certificate for

Table 4.1 Means (standard deviation) of production and outdoor run parameters on Farm 1, 2 and 3.

	(unit)	Farm 1	Farm 2	Farm 3
Production				
Feed intake as fed	(g hen^{-1} d^{-1})	124 (19.0)	122 (13.3)	125 (12.5)
Concentrate share in ration	(%)	79.2 (12.7)	73.2 (5.3)	62.5 (2.7)
CCM share in ration[a]	(%)	-	6.0 (7.3)	7.5 (8.0)
Wheat share in ration	(%)	20.8 (13.1)	20.8 (5.2)	30.0 (8.5)
Produced egg mass	(g hen^{-1} d^{-1})	52.0 (5.45)	52.3 (5.40)	52.1 (2.95)
Flock size	(#)	2,948 (104)	6,040 (111)	2,743 (201)
Outdoor run				
Surface size Zone 1[b]	(m^2)	222 (-)	698 (-)	269 (-)
Surface size Zone 2[b]	(m^2)	496 (-)	940 (-)	815 (28)
Surface size Zone 3[b]	(m^2)	5,358 (603)	9,250 (-)	4,610 (754)
Maximum distance[c]	(m)	99	257	141
Time access to outdoor run	(h d^{-1})	9.00 (2.20)	8.25 (0.41)	11.1 (1.88)

[a] CCM = corn cob maize.

[b] Included surface of the outdoor run in the experiment, i.e. surfaces unvisited by the hens and temporarily fenced off surfaces for vegetation recovery were excluded.

[c] Distance between the entrance of the winter garden and the furthest location in the outdoor run.

more than four years; and had used the outdoor run for at least one production round. Flock size was recorded during each measurement, because flock size (Table 4.1) decreased slightly during the production round due to mortality.

Measurements took place between October 2008 and February 2010. Four measurements, one per season, were executed on each farm, to include as much as possible the effects of outdoor weather conditions, indoor climate, day length, rearing management, age, genotype, and stage of the production round. Measurements started at a random stage of the production round, and thus included the replacement of the flock once on each farm during the experiment. No measurements were executed until eight weeks after the laying hens were purchased (at an age of 17 weeks), to allow hens to get used to the husbandry system.

A measurement lasted three days. At the start of the measurement manure and feed was sampled to determine content of N and P, and mass of a single manure dropping. On the first two days we measured total number and distribution of hens in the outdoor run. On the third day we measured rate of excretion of manure droppings by hens in the outdoor run. During each measurement the farmer filled in a questionnaire regarding production and management characteristics.

Before the measurements started, the outdoor run of each farm was divided in three zones: zone 1, located 0 to 10 meters from the hen house; zone 2, located 10 to 25 meters from the hen house; and zone 3, located 25 metres and more from the hen house. The surface size of the zones of each farm are given in Table 4.1. Borders of zones were marked with sticks. At the start of a measurement three plots were placed in each zone. The location of plots differed between measurements, but not between days of a measurement. Each zone was divided in nine blocks of three rows and three columns. One plot was assigned to each row and each column to spread plots within a measurement evenly over the width and length of a zone. Each block contained a plot at least once. The location (x, y coordinate) of a plot within a block was assigned at random on a map of the outdoor run. The shortest distance between the centre of each plot and the entrance of the winter garden was determined at the start of the measurement.

Plots were four by four meters and marked with one meter high palls between which a white nylon cord was tightened at ground level. Influence of chords and palls on hen distribution was visually tested during a pilot experiment and was minimal if loose ends of chords were removed. An observation chair (i.e. a chair on a ladder at 3.0 m height) was placed in the outdoor run on the border of zone 1 and 2 a few weeks before the measurements started, at a distance of at least 5 m from the nearest plot. The observer mounted the observation chair before hens accessed the outdoor run. If more than ten hens were present in a plot simultaneously or when hens were too mobile to count instantaneously, a photograph was taken and hens were counted at a later moment from the photograph.

4.2.2. Farm characteristics

Inside the house, hens had ad libitum access to water and feed. Feed was a mixture of organic concentrate and corn cob maize (daily feed intake and shares of feedstuffs are given in Table 4.1). On farm 1 and 3, wheat was added to the feed. From approximately noon until shortly after sunset curtains between winter garden and outdoor run were opened over the full width of the hen house and hens could access the outdoor run (access time is in Table 4.1). Hens included in the experiment were separated from hens in other compartments or houses with fences placed around the outdoor run and walls in the hen house and winter garden.

On organic farms hens are offered four m^2 per hen in the outdoor run. We excluded parts of the outdoor run that were fenced off temporarily for vegetation recovery and remote, unvisited areas of the outdoor run from the experiment. The mean surface per hen in the outdoor run included in the experiment, therefore, was 2.06 on farm 1, 1.80 on farm 2, and 2.08 m^2 on farm 3. The shortest distance between the curtain of the winter garden and the furthest spot in the outdoor run was measured (Table 4.1).

4.2.3. Content of N and P, and mass of a single manure dropping

One sample of fresh manure was collected during each measurement (n=12). Approximately 25 manure droppings were collected by removing manure every two hours from a clean plastic board placed on the wired surface above one of the manure belts in the hen house. The number and total mass of collected manure droppings was measured. Samples were stored in closed containers at a temperature of 5 ˚C until analysis. Pre-treatment of samples included: homogenization, addition of tartaric acid (to fix ammonium), drying and grinding. Samples were analysed for dry matter (DM) (gravimetric), total N (distillation) and P (photometric). One sample from farm 2 was lost (11 remaining).

We calculated mass of a manure dropping by dividing total mass of the sample by the number of droppings. We tested the effect of the factor farm on content of N and P, and on mass of a manure dropping with analysis of variance.

4.2.4. Rate of excretion of manure droppings by hens in the outdoor run

During each measurement we determined the rate of excretion of manure droppings by hens in the outdoor run in each plot (n=108). The procedure was: remove all manure droppings from the assigned plot in each zone, count hens in the three plots from the observation chair every five minutes for a period of one hour, enter the outdoor run and count the number of manure droppings in the three plots, and note the time between cleaning and counting for each plot. We repeated this procedure two times to collect data from each of the nine plots.

We calculated the hourly mean number of hens in a plot from the 12 five-minute observations and the hourly number of excreted faeces droppings in a plot, by dividing the number of counted droppings by the time span (hours) between cleaning and counting of droppings. Rate of excretion of manure droppings by hens in the outdoor run of each farm was obtained by dividing mean number of excreted droppings per hour of each farm by mean number of hens in a plot of each farm (n=36).

4.2.5. Total number and distribution of hens in the outdoor run

During two days the number of hens in each of the nine plots was counted every 30 minutes during the period hens had access to the outdoor run. The first counting was executed at a randomly chosen moment within the first 30 minutes, and subsequent counts were executed with a 30 minute time interval. This observation regime was chosen to take into account the massive movement of hens into the hen house induced by the sound of the feed system. We calculated the mean daily number of hens in each plot from the 30 minute interval observations.

We formulated a Generalized Linear Mixed Model to predict the log mean daily number of hens in a plot (Equation 1). We used a Poisson distribution. We included the fixed effects: farm, distance of a plot to the entrance of the winter garden, and farm effect on distance of plot to the entrance of the winter garden. We included the random terms plot, measurement (four two-day periods per farm) and farm. The model was:

$$\log (E(Y_{hijk})) = \beta_0 + \gamma_{0h} + (\beta_1 + \gamma_{1h}) * D + p_j + m_k + m_k * f_h + m_k * p_j \qquad (1)$$

Where $E(Y_{hijk})$ is the expected mean number of hens counted on farm h, in zone i, in plot j, during measurement k; β_0 is the intercept constant; γ_{0h} is the fixed effect of farm h; β_1 is the effect of distance; γ_{1h} is the fixed effect of farm h on distance; D is the shortest distance from the centre of a plot to the curtain of the winter garden (m); p_j is the random effect of plot j; m_k is the random effect of measurement k; and f_h is the random effect of farm h.

We calculated mean number of hens per plot for each distance on each farm (Equation 1) and obtained the hen density (hens m^{-2}) by dividing with 16 (i.e. surface of a plot in m^2). Mean hen density in a zone was calculated from hen density at all possible distances from the winter garden in a zone, (e.g. 0 to 9 m for zone 1). We multiplied hen density with the surface of a zone to determine total number of hens in a zone.

4.2.6. Excretion of N and P

Excretion of N and P in manure per day was estimated with a mass balance by subtracting N and P in egg production from N and P in consumed feed. Content of N and P in feed was determined by grab sampling the feed (i.e. the offered mixture of organic concentrate, corn cob maize and wheat) just before it entered the feeders and analysed in the same way as manure. Content of N and P of eggs was obtained from literature (Jongbloed and Kemme, 2005). Feed intake and produced egg mass per hen per day for each measurement day and farm were known from the questionnaire. Retention of N and P in growth of laying hens was assumed to be negligible. We calculated excretion of N and P per hen per day for each measurement period on each farm as

$$E_{hk} = C_{fhk} * M_{fhk} - C_e * M_{ehk} \quad (2)$$

Where E_{hk} is the excretion of N or P (g hen^{-1} d^{-1}) on farm h, during measurement period k on that farm; C_f is the content of N or P of the feed (g g^{-1}); M_f is the feed intake (g hen^{-1} d^{-1}); C_e is the content of N or P of eggs (g g^{-1}); M_e is the produced egg mass (g hen^{-1} d^{-1}).

We tested the effect of farm on estimated excretion of N and P, content of N and P of the feed, feed intake and produced egg mass with analysis of variance.

4.2.7. Load and total mass of N and P on the outdoor run

Load of N and P at a specific distance from the hen house in the outdoor run was calculated as

$$L_{hd} = Y_{hd} * H_h * t_h * M_h * C_h * 104 \quad (3)$$

Where L_{hd} is the load of N or P in the outdoor run on farm h at distance d (kg ha^{-1} d^{-1}); Y_{hd} is the hen density on farm h at distance d (hens

m^{-2}); H_h is the mean number of manure droppings excreted per hen per hour in the outdoor run on farm *h*; t_h is the time period the outdoor run is accessible on farm *h* (h d^{-1}); M_h is the mass of a single manure dropping on farm *h* (kg); C_h is the content of N or P of manure on farm *h* (g g^{-1}); 104 is the conversion constant from m^2 to ha.

Mean load of N and P in a zone was the mean of the N and P load at all possible distances from the winter garden in a specific zone on a specific farm. To compare the load we measured with load measured by Aarnink et al. (2006) we converted daily load (kg ha^{-1} d^{-1}) to yearly load by multiplication with 335 days, thereby including a zero occupancy period of 30 days between cycles and during the first weeks of a production round when hens have no access to the run.

Total mass of N and P (kg d^{-1}) excreted outside was calculated for each zone as well as for the entire outdoor run of each farm. Total mass of N and P excreted into a zone was calculated by multiplying the mean load of N and P in a zone with the surface size of the zone. Total mass of N and P excreted into the entire outdoor run of each farm was calculated by summing mass of N and P excreted in zone 1, 2, and 3.

Excreted mass of N and P on each farm in each zone and for the entire outdoor run was also calculated as a share of the total daily excretion of N and P. Share of N and P was calculated by dividing the total mass of N and P excreted (in a zone or the entire outdoor run) with farm specific flock size and N and P excretion per hen per day.

4.3. Results

4.3.1. Content of N and P, and mass of a manure dropping

Mean content of N and P of fresh manure droppings was 14.0 g N kg^{-1} (SE 0.50) and 3.12 g P kg^{-1} (SE 0.14), mean mass of a dropping was 6.36 g (SE 0.64) and mean DM content of a dropping was 238 g kg^{-1} (SE 9.1). Farm specific mean content of N, P and DM of fresh manure droppings, mass of a dropping are in Table 4.2. Analysis of variance showed a difference among farms for content of N of a dropping ($P<0.05$), but not for content of P ($P=0.11$), mass of a dropping ($P=0.34$) and DM content of a dropping ($P=0.68$).

4.3.2. Rate of excretion of manure droppings by hens in the outdoor run

Mean number of observed hens in a plot (n=108) was 2.56 hens (SE 0.55). Mean number of droppings per hour was 7.65 (SE 1.14). Mean rate of

Table 4.2 Farm specific estimated means (standard deviation) for calculation of the N and P load of the outdoor run.

	(unit)	Farm 1		Farm 2		Farm 3	
Content of N of feed	(g kg^{-1})	27.4	(3.67)	29.3	(1.60)	30.1	(2.40)
Content of N of egg	(g kg^{-1})	0.0185[a]		0.0185[a]		0.0185[a]	
Content of N of fresh manure	(g kg^{-1})	15.35	(1.44)	14.37	(0.72)	12.39	(1.31)
Content of P of feed	(g kg^{-1})	5.06	(0.85)	5.66	(0.54)	6.04	(1.02)
Content of P of egg	(g kg^{-1})	0.0017[a]		0.0017[a]		0.0017[a]	
Content of P of fresh manure	(g kg^{-1})	2.81	(0.58)	3.57	(0.28)	3.10	(0.25)
DM content of fresh manure	(g kg^{-1})	230	(31.5)	235	(31.1)	250	(33.6)
Mass of a dropping	(g)	6.90	(2.41)	4.99	(1.83)	7.26	(2.30)
Production rate of a dropping	(nr h^{-1})	2.48	(2.08)	5.66	(6.51)	3.16	(0.07)
N excretion	(g hen^{-1} d^{-1})	2441	(396)	2692	(421)	2893	(398)
P excretion	(mg hen^{-1} d^{-1})	536	(50)	616	(104)	661	(134)

[a] According to Jongbloed and Kemme (2005).

excretion of manure droppings in the outdoor run, therefore, was 2.99 droppings per hen per hour. Farm specific mean rates of excretion of manure droppings in the outdoor run are in Table 4.2.

4.3.3. Total number and distribution of hens in the outdoor run

Estimated model parameters (Equation 1) to predict the log mean daily number of hens in a plot are given in Table 3. There was a significant linear effect of distance (β_1; P<0.001). This effect of distance differed between farms ($\beta_1 + \gamma_{1h}$; P<0.001). Farm effect on the intercept was not significant (γ_{0i}; P=0.40). The model had an over dispersion of 2.0, indicating that hens had a tendency to group.

On all farms we found an exponential decrease of the number of hens in a plot with increasing distance from the hen house (Fig. 4.1). At a distance of zero meters the estimated hen density was lowest on farm 1 (0.23 hen m^{-2}), highest on farm 2 (0.32 hen m^{-2}) and intermediate on farm 3 (0.26 hen m^{-2}). Mean hen density in a zone varied among farms from 0.14 to 0.29 hens m^{-2} in zone 1, 0.03 to 0.11 hens m^{-2} in zone 2, and 0.001 to 0.04 hens m^{-2} in zone 3. Hen density decreased fastest with distance on farm 1 (0.01 hen m^{-2} at 22 m), least on farm 2 (0.01 hen m-^{2} at 147 m), and intermediate on farm 3 (0.01 hen m^{-2} at 54 m).

Mean percentage of hens outside, during the time the outdoor run could be accessed, was lowest on farm 1 (1.7%), highest on farm 2 (13.0%), and intermediate on farm 3 (7.1%) (Table 3). On farm 1 most hens were located in zone 1 (1.0%), on farm 2 in zone 3 (6.0%), and on farm 3 in zone 2 (3.2%).

4.3.4. Excretion of N and P

Mean estimated excretion per hen per day was 2.68 g (SE 0.115) for N and 0.605 g (SE 0.031) for P. Farm specific excretion of N and P, N and P content of eggs and feed, feed intake and produced egg mass are in Table 4.2. Analysis of variance showed no significant effect of farm on: excretion of N (P=0.30) and P (P=0.27) per hen per day, content of feed of N (P=0.38) and P (P=0.29), feed intake (P=0.92) and produced egg mass (P=0.44). The excretion of N and P amounted 69% to 76% of the total N and P intake.

4.3.5. Load of N and P on the outdoor run

On all farms we found an exponential decrease of the load of N and P with an increasing distance from the hen house (Fig. 4.2 and 4.3). Load of N at a distance of zero m was lowest on farm 1 (5.35 kg N and 0.98 kg P ha^{-1} d^{-1}),

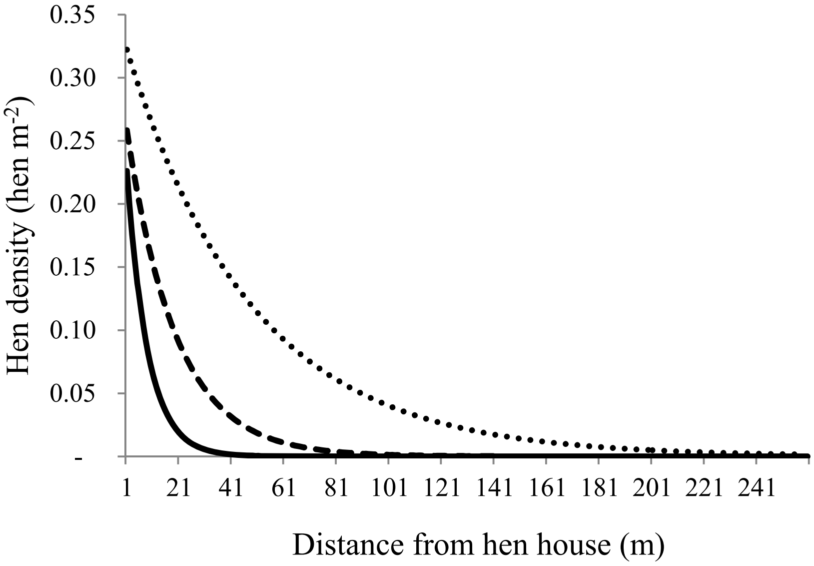

Figure 4.1 Relation between hen density in the outdoor run and distance from the hen house on farm 1 (line), 2 (dots) and 3 (dashes), based on Equation 1.

Table 4.3 Estimated model parameters (Equation 1) to predict the log mean daily number of hens in a plot. Means and standard errors (SE) of fixed effects are given: β_0 the intercept constant, γ_{0h} farm effect on intercept relative to farm 1, β_1 linear effect of distance, γ_{1h} farm effect on linear effect of distance relative to farm 1.

Parameter	Mean	SE
β_0	1.2860	0.5454
γ_{01}	0.0000	0.5885
γ_{02}	0.3541	0.5885
γ_{03}	0.1333	0.5885
β_1	-0.1252	0.0341
$\beta_1 + \gamma_{11}$	0.0000	0.0267
$\beta_1 + \gamma_{12}$	0.1043	0.0267
$\beta_1 + \gamma_{13}$	0.0721	0.0267

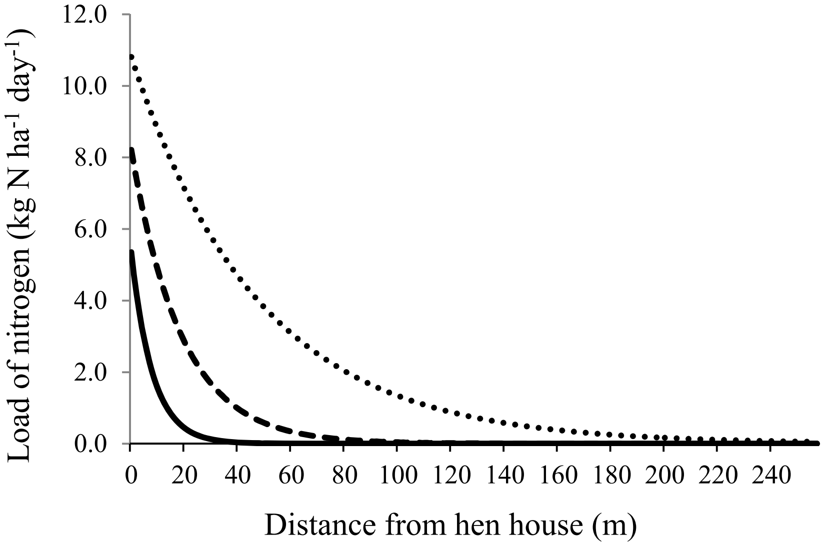

Figure 4.2 Relation between load of nitrogen in the outdoor run and distance from the entrance of the winter garden on farm 1 (line), 2 (dots), and 3 (dashes), based on Equation 3.

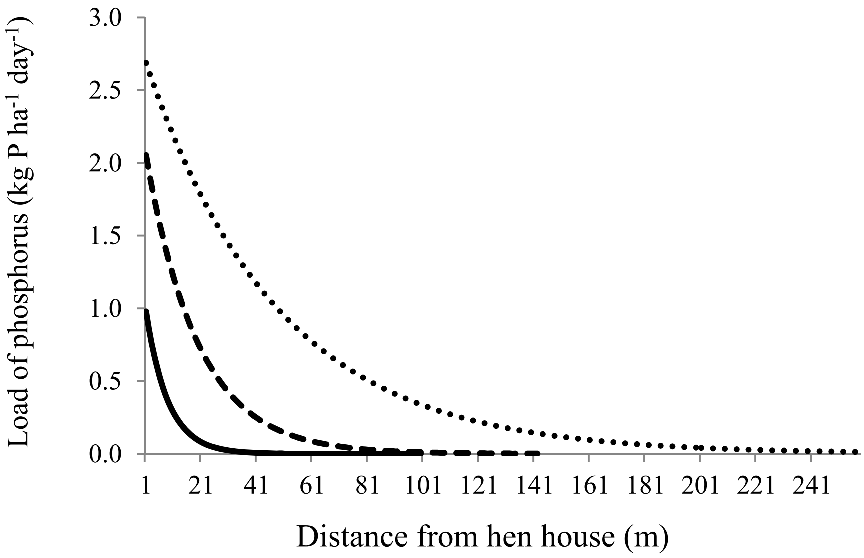

Figure 4.3 Relation between load of phosphorus in the outdoor run and distance from the entrance of the winter garden on Farm 1 (line), 2 (dots), and 3 (dashes), based on Equation 3.

intermediate on farm 3 (8.21 kg N and 2.05 kg P ha^{-1} d^{-1}), and highest on farm 2 (10.81 kg N and 2.69 kg P ha^{-1} d^{-1}). Load of N and P decreased with distance: fastest on farm 1, least on farm 2, and intermediate on farm 3.

4.3.6. Total mass of N and P excreted into the outdoor run

On farm 1 total mass of N excreted into the outdoor run was lowest (124 g N d^{-1} and 1.7% of total N excretion), on farm 2 highest (2,106 g N d^{-1} and 16.1%) and on farm 3 intermediate (564 g N d^{-1} and 7.8%). Results for P were similar (Table 4). On farm 1 most N and P was excreted in zone 1, on farm 2 in zone 3 and on farm 3 in zone 2.

4.4. Discussion

4.4.1. Total excretion and content of N and P, and mass of a manure dropping

In this study measured N-P ratio from manure samples (4.49 g N to 1 g P) was almost equal to calculated ratio from daily excretion of N and P (4.43 g N to 1 g P). This indicates that samples were very fresh and well conserved, because no ammonia or other N-gases seemed to have volatilized from the samples. Data analysis showed a significant difference among farms in content of N of fresh manure.

Mean content of N of a manure dropping (14.0 g N kg^{-1}) was in the range of content of N of fresh manure in non-organic laying hen husbandry (13 to 17 g N kg^{-1}) (Groot Koerkamp, 1994). Mean mass of a single manure dropping in this research (6.4 g) was a little lower than mass of fresh manure droppings (6.8 g) collected in the outdoor run from a soil surface on a commercial organic farm (Aarnink et al., 2006). Content of DM of droppings in our study (238 g kg^{-1}) was in the range of what was reported as typical for fresh manure (200 to 250 g kg^{-1}; Groot Koerkamp, 1994), but considerably lower than in the study of Aarnink et al. (2006) (357 g kg^{-1}), while content of N (14.0 g N kg^{-1}) and P (3.12 kg P kg^{-1}) were higher than content of N (9.8 g N kg^{-1}) and P (2.4 g P kg^{-1}) in the study of Aarnink et al. (2006). The reason for the higher DM content and lower content of N and P in the study of Aarnink et al. (2006) might have been caused by differences in feed composition or drying of the samples before collection.

4.4.2. Rate of excretion of manure droppings by hens in the outdoor run

Rate of production of manure droppings per hen has not yet been published. A hen typically produces 160 to 180 g manure per day, depending on DM content of fresh manure (Groot Koerkamp, 1994). We measured a rate of excretion of manure droppings in the outdoor run of 2.99 droppings per hen per hour with a mean mass of 6.36 g per dropping. This implies a higher manure excretion rate (19.02 g hen^{-1} h^{-1}) in the outdoor run than the daily mean manure excretion rate (170 g hen^{-1} d^{-1} or 7.08 g hen^{-1} h^{-1}) (Groot Koerkamp, 1994). Excretion rate may be higher during the afternoon, because hens consume most feed and water in the morning and mean retention time of feed in the intestinal tracks is approximately 190 minutes (Van Krimpen et al., 2012); or hens may have a behavioural preference to excrete manure outside.

4.4.3. Total number and distribution of hens in the outdoor run

In this study percentage of hens outside (1.7% to 13.0%) was lower than in other studies with flocks of 2000 to 3000 hens (5% to 25%) (Bubier and Bradshaw, 1998; Hegelund et al., 2005; Hegelund et al., 2006). From these studies we know that the percentage of hens in the outdoor run can vary considerably between farms. Percentage of hens outside in this study may have been low compared to other studies, because observations were, in contrast to other studies, executed: year round, occasionally under bad weather circumstances, and during the entire time period hens had access to the outdoor run. Another reason for low percentages of hens outside may have been farm or flock specific characteristics, such as: genotype (Elwinger et al., 2008); rearing management (Bestman and Wagenaar, 2003; Grigor et al., 1995; Mirabito and Lubac, 2001); weather and climate (Elwinger et al., 2008; Hegelund et al., 2005) and layout of the outdoor run and presence of natural or artificial objects (Harlander-Matauschek et al., 2006; Zeltner and Hirt, 2003). The low percentage of hens outside on farm 1 (1.7%) may have been caused by a complete lack of natural or artificial shelters. The relatively high percentage of hens outside on farm 2 (13%) may have been caused by the transparent curtains to the winter garden and to the outdoor run, causing a small difference in light intensity between outside and inside the hen house. Furthermore, on this farm bushes and trees were present in the outdoor run and hens were reared on the same farm in a comparable hen house with consequent access to an outdoor run from an age of seven weeks onwards.

As reported in other studies, hen density decreased with distance from the winter garden. We found that this decrease was exponential. Initial hen density (at zero m) and the magnitude of the decrease differed among farms. In our study, hardly any hen (0.01 hen m^{-2}) was present in the distance range from the winter garden of 22 m to 99 m at farm 1, of 157 m to 257 m at farm 2, and of 54 m to 141 m at farm 3. This means that 39% to 78% of the area of the outdoor run included in this study (i.e. we already excluded remote parts of the outdoor run) remained almost unused. The area close to the hen house, on the other hand, was overused and, consequently, all vegetation was destructed by intensive foraging, with the exception of large bushes and trees. The area with a medium hen density was relatively small, because hen density decreased exponentially with distance. The relative gradual exponential decrease of hen density with distance on farm 2, which offered shelter by trees and bushes, resulted in: the highest initial hen density (at zero m), most hens outside, a more gradual decrease of hen density with distance from the main shelter (the hen house) and a larger maximum distance of the outdoor run used by the hens.

Outdoor runs are intended to stimulate behaviours of exploration, running, flying, foraging, sunbathing, and dust bathing. However, as long as hens do not feel safe in the outdoor run, because of a lack of shelter, it seems that the execution of this behaviour is limited to a few ‘reckless’ hens and these hens may be under continuous stress.

4.4.4. Load and total mass of N and P on the outdoor run

Our estimation of the mean load of N and P in the region of 0 to 20 m from the winter garden was 673 kg N ha^{-1} y^{-1} for farm 1; 2,961 kg N ha^{-1} y^{-1} for farm 2; and 1,702 kg N ha^{-1} y^{-1} for farm 3. Mean load of P in the region of 0 to 20 m from the winter garden was 123 kg P ha^{-1} y^{-1} for farm 1; 736 kg P ha^{-1} y^{-1} for farm 2; and 426 kg P ha^{-1} y^{-1} for farm 3. Mean load of N and P in the same distance measured by Aarnink et al. (2006) ranged from 2,412 to 2,845 kg N ha^{-1} y^{-1} and 552 to 709 kg P ha^{-1} y^{-1}. On farm 1 and 3 in this study mean load of N and P was lower than measured by Aarnink et al. (2006), whereas mean load of N and P of farm 2 was comparable to Aarnink et al. (2006). Higher loads of N and P may be caused by higher hen densities in the outdoor run and by the fact that the measurements of Aarnink et al. (2006) were executed in summer only, when weather conditions are more favourable for hens to go outside than in winter. Furthermore, in two out of three studied farms of Aarnink et al. (2006), flock size was only 500 to 600 hens and the relative number of hens outside increases with a decrease of the flock size (Hegelund et al., 2005).

Pasture has a fertilization standard of 170 kg N ha^{-1} y^{-1} and 100 kg P ha^{-1} y^{-1} (KWIN-V, 2007). Load of N will exceed this fertilization standard at a lower hen density than load of P, because N-P ratio of fresh manure was

4.49:1 and N-P ratio of the fertilization standard for pasture is 1.7:1. If we assume that hens use the outdoor run for 335 days per year (i.e. due to replacement of the flock) load of N may not exceed 0.507 kg ha^{-1} d^{-1}. In our study load of N exceeded the fertilization standard in the region of 0 to 19 m on farm 1, 0 to 146 m on farm 2 and 0 to 52 m on farm 3. In the areas further away from the hen house, however, the load of N was lower than the fertilization standard. The fertilization standard is used for intensive pasture production. Uptake capacity of N and P by pasture in the outdoor run is unknown and will be variable depending on forage intensity of the hens. In regions of the outdoor run with high hen density crop growth is limited, because vegetation is destructed by intensive foraging, while in these regions load of N and P is high. In regions with a low hen density, on the other hand, vegetation is less destructed, but also hardly any N and P is excreted. The region with an intermediate hen density is small due to exponential decrease of load of N and P with distance from the hen house. Load of N and P on the outdoor run, therefore, is unbalanced and should be levelled out. Hen density exceeded the fertilization standard at a hen density of 0.021 hens m^{-2} on farm 1, 0.015 hen m^{-2} on farm 2 and 0.016 hens m^{-2} on farm 3. We estimate that the N fertilization capacity of the entire outdoor run (4.0 m^2 hen^{-1}) is exceeded, if more than 7.0% of the hens are outside (mean hen density of all farms is 0.018 hens m^{-2} divided by 0.25 hens m^{-2}). In this study this was the case on farm 2 and 3.

Total mass of N and P excreted into the outdoor run varied between 1.7% and 16.1% of the total N excretion and 1.4% and 17.5% of the total P excretion. In single tiered houses, (the most common housing for organic laying hens) N loss as ammonia (NH_3) from the hen house is much higher than N loss from the outdoor run, i.e. 36.3% (NH_3-N) of the total N excretion (Dekker et al., 2011a). From aviary systems, however, N loss from the hen house is in the same range as N loss from to the outdoor run, i.e. 12.6% of the total N excretion (i.e. 0.329 g NH_3-N hen^{-1} d^{-1}) (Dekker et al., 2011b). This comparison shows that reduction of loss of N and P in the outdoor run can have a relevant contribution to retention of N and P in the organic production cycle.

4.4.5. Possible solutions

There may be two options to solve the problem of high nutrient losses in the outdoor run. The first option is removal of the manure from the outdoor run or redistribution of manure from the overloaded areas to other areas of the outdoor run or other arable land. A second option is to distribute hens more evenly over the outdoor run at a low hen density.

Table 4.4 Farm and zone specific; surface size of the outdoor run, number of hens in the outdoor run, percentage of hens outside, mass of N and P excreted in the outdoor run and percentage of N and P excreted outside.

				Mass of excretion			
	Surface size	Hens in outdoor run		Mass per zone		Share of total excretion	
	(m^2)	(nr)	(%)	(g N d^{-1})	(g P d^{-1})	(% of N)	(% of P)
Farm 1							
Zone 1	222	30	(1.0)	74.4	16.3	1.0	0.8
Zone 2	496	15	(0.5)	37.6	8.25	0.5	0.4
Zone 3	5,358	5	(0.2)	11.9	2.62	0.2	0.1
Total outside	6,076	51	(1.7)	124	27.2	1.7	1.4
Farm 2							
Zone 1	698	205	(3.4)	552	126	4.2	4.6
Zone 2	940	213	(3.5)	574	131	4.4	4.8
Zone 3	9,250	364	(6.0)	980	224	7.5	8.2
Total outside	10,888	782	(13.0)	2,106	482	16.1	17.5
Farm 3							
Zone 1	269	55	(2.0)	160	36.6	2.2	2.4
Zone 2	815	88	(3.2)	254	58.0	3.5	3.8
Zone 3	4,610	52	(1.9)	151	34.4	2.1	2.3
Total outside	5,694	195	(7.1)	564	129	7.8	8.6

Possibilities for removal of manure are: replacing soils by solid floors and collect manure from these floors; regular exchange of the soil near the hen house with clean soil from remote parts of the outdoor run; drainage of soil water combined with recovery of N and P; drainage of soil water combined with irrigation of this water on the remaining part of the outdoor run. Feasibility of these methods, however, depends on costs, farm characteristics (e.g. number of hens outside), regulation and revenues for manure or savings of fertilizer.

Another option for the long run could be to redesign the outdoor run in such a way that the outdoor run would have the purpose of feeding the laying hens. Therefore the available surface per hen should be larger depending on the part of the ration that the hens need to take up by foraging. The outdoor run would be planted with a mixture of high vegetation such as maize or grain, which are not harvested. In this situation hens are fed either by strip grazing in combination with a mobile hen house or hens are fed by switching between different small outdoor runs located around several small hen houses (Horsted et al., 2006; Keeling et al., 1998).

4.5. Conclusion

Despite the low percentage of hens outside, varying on average from 1.7% to 13.0% among farms, overloading of the outdoor run with N and P occurred near the hen house. Total mass of N and P excreted into the outdoor run varied from 1.7% to 16.1% of total N and 1.4% to 17.5% of total P excretion.

The load of N and P in the outdoor run decreased exponentially with distance from the hen house, caused by the exponential decrease of hen density and resulting excretion of manure. The fertilization standard of 170 kg N per year, used for intensive pasture, was exceeded within distances from the hen house varying from 19 to 146 m. The husbandry system for organic laying hens should be redesigned to solve the problem of overloading, unwanted losses of N and P to the environment, and N and P loss from the organic production cycle.

Acknowledgements

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Chapter 5

Effect of origin and composition of diet on ecological impact of the organic egg production chain

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Abstract

The objective of this research was to assess the potential to reduce the integral ecological impact (i.e. impact along the egg production chain per kg egg) of Dutch organic egg production by replacing currently used imported diet ingredients with Dutch diet ingredients. We realized this objective by comparing the life cycle assessments of current Dutch organic egg production (i.e. base situation) with different scenarios. In each scenario, one imported diet ingredient was replaced with a diet ingredient produced in the Netherlands. Finally, we formulated a scenario in which several ingredients, that individually resulted in the lowest mean change in ecological impact along the organic egg production chain, were replaced simultaneously. We included differences between production chains in cultivation (i.e. field operation, manure application and yield), transport, feed intake, egg production and N excretion.

Replacement of Ukrainian wheat with Dutch triticale, and of Brazilian soy beans, Italian sunflower seed expeller and German peas with Dutch rapeseed expeller reduced the integral ecological impact compared with current organic egg production. Simultaneous replacement of these ingredients (scenario MU) resulted a lower mean ecological impact (80.6%) than single replacement of these ingredients (93.5% to 111.9%). Compared with current egg production (B) ecological impact of scenario MU decreased for global warming potential (91%), energy use (79%), land occupation (68%), acidification potential (99%), N deficit (85%), P deficit (41%) and P surplus (81%), but slightly increased for N surplus (101%). The low ecological impact of MU was explained by: 1) a reduction of the transport distance of 44.4% of the diet ingredients, 2) replacement of current used crops with crops that have a higher yield in combination with a balanced applied amount of N and P in manure, and 3) use of expeller instead of whole ingredients, despite a relative small increase of the feed conversion (from 2.32 kg feed kg^{-1} egg for B to 2.37 kg feed kg^{-1} egg for MU).

Nomenclature	
E	apparent metabolizable energy intake in kCal
EM_i	egg mass produced
G	growth rate
M_i	the digestible methionine intake from diet i
T	environmental temperature

Abbreviations	
AMEn	apparent metabolizable energy
B	current egg production system
DM	dry matter
eq.	equivalent
LCA	life cycle assessment
MG	scenario that replaces Italian maizeglutenmeal with Dutch alfalfa silage
MU	scenario that replaces Ukrainian wheat with Dutch triticale, and Brazilian soy beans, Italian sunflower seed expeller and German peas with Dutch rapeseed expeller
M1	scenario that replaces Italian maize with Dutch maize
M2	scenario that replaces Italian maize with Dutch corn cob mix
P1	scenario that replaces German peas with Dutch rapeseed expeller
P2	scenario that replaces German peas with Dutch horse beans
P3	scenario that replaces German peas with Dutch lupines
P4	scenario that replaces German peas with Dutch alfalfa silage
SE1	scenario that replaces Ukrainian sunflower expeller with Dutch rapeseed expeller
SE2	scenario that replaces Ukrainian sunflower expeller with Dutch alfalfa silage
S1	scenario that replaces Brazilian soy bean expeller with Dutch rapeseed expeller
S2	scenario that replaces Brazilian soy bean expeller with Dutch horse beans
S3	scenario that replaces Brazilian soy bean expeller with Dutch lupines
S4	scenario that replaced Brazilian soy bean expeller with Dutch alfalfa silage
W1	scenario that replaces Ukrainian wheat with Dutch rapeseed expeller
W2	scenario that replaces Ukrainian wheat with Dutch horse beans
W3	scenario that replaces Ukrainian wheat with Dutch lupines
W4	scenario that replaces Ukrainian wheat with Dutch alfalfa silage

5.1. Introduction

European Union legislation states that organic farming should avoid environmental pollution (EC, 1999b) and the International Federation of Organic Agriculture Movements states that ecology is one of the basic principles of organic farming (Luttikholt, 2007). This implies that organic egg production chains should have a lower integral ecological impact (i.e. impact per kg egg along the egg production chain) than conventional systems regarding ecological issues, such as global warming, fossil energy depletion, land occupation, acidification, eutrophication and soil depletion (Steinfeld et al., 2006; De Vries and de Boer, 2010).

Ecological impact of the egg production chain is determined mainly by cultivation of diet ingredients, emissions from laying hen manure, and transport of ingredients, hens and manure (Dekker et al., 2011b). In organic egg production, cultivation and processing of organic diet ingredients contributes 41% to global warming, 50% to fossil energy use, 95% to land occupation, 28% to acidification and 99% to N and P deficit and surplus (i.e., a negative or positive N and P balance resulting from cultivation); whereas transport of diet ingredients, hens and manure contributes 17% to global warming, 36% to energy use and 10% to acidification (Dekker et al., 2011b). Ecological impact of organic eggs, therefore, may be reduced by altering production and transport of diet ingredients.

Moreover, Dekker et al. (2011b) shows that organic egg production has a lower ecological impact than conventional loose egg production regarding global warming (-4%), energy use (-10%), N surplus (-88%) and P surplus (-91%), but a higher impact regarding acidification (+20%), land occupation (+80%) and N (+1325%) and P deficit (+900%). These differences result from prohibition of artificial fertilizer in organic farming, limited use of manure, few field operations during cultivation of diet ingredients and low yields per hectare (Dekker et al., 2011b). Moreover, organic hens show a less efficient conversion of feed to eggs (i.e. feed conversion of 2.6 kg feed kg^{-1} egg) compared with conventional loose housed hens (2.3 kg feed kg^{-1} egg; Dekker et al., 2011b). Less efficient feed conversion negatively affects the integral ecological impact of organic egg production. Higher feed conversion of organic hens results from a higher energy requirement and an unbalanced amino acid profile of the diet (i.e. digestible lysine and methionine). Energy requirement of hens in organic husbandry may be higher than in conventional husbandry because of: 1) a higher level of activity of hens (caused by more space in the hen house and access to an outdoor run); 2) a lower health status due to limited use of medicines; 3) a lower temperature in the house (due to lower stocking density and higher ventilation rates) and outdoor run; 4) a worse plumage condition due to untrimmed beaks. The amino acid profile of organic diets is unbalanced, because industrial produced amino acids and chemical extracted protein sources are not allowed in organic farming. Current options to reduce energy requirement of the hen or to balance the amino acid profile of the diet, within the ethical and regulatory boundaries of organic farming are limited (Van Knegsel and van Krimpen, 2008).

A feasible option to reduce integral ecological impact of organic egg production is to reduce ecological impact of production and transport of organic diet ingredients (Dekker et al., 2011b). This option might be realized by replacing imported diet ingredients with regional ones. These regional ingredients, however, should have a comparable energy and protein content as the imported ingredients to achieve a similar feed conversion. Replacing imported diet ingredients with regional diet ingredients might affect the ecological impact of organic egg production in four ways.

First, the amount of manure applied varies between regions and crops. An increase of the amount of manure applied per hectare, for example, increases the N and P balance in the soil, i.e. N and P surplus and deficit; emissions of nitrous oxide (N_2O) per hectare, i.e. global warming; and emission of ammonia (NH_3) per hectare, i.e. acidification. Second, the intensity of field operations per hectare varies between regions and crops. More field operations per hectare, for example, increases energy use and emission of carbon dioxide (CO_2) per hectare, i.e. global warming. Increase of the amount of manure applied and intensity of field operation, however, also increases yield per hectare and, therefore, has a reducing effect on the ecological impact per kg of diet ingredient produced. Third, distance of transport of diet ingredients decreases, which lowers global warming and energy use. Fourth, changes in diet composition might affect feed conversion and subsequently ecological impact. A decrease in energy content of the diet, for example, increases feed intake. An increase in methionine intake, increases egg production (Van Krimpen et al., 2011).

Whether the integral the integral ecological impact of organic eggs will increase or decrease when imported diet ingredients are exchanged for Dutch diet ingredients is unknown. The objective of this research is to assess the potential to reduce the integral ecological impact (i.e. impact along the egg production chain per kg egg) of Dutch organic egg production by replacing currently used imported diet ingredients with Dutch diet ingredients. We realized this objective by comparing the life cycle assessments (LCA) of current Dutch organic egg production (i.e. base situation) with different scenarios. In each scenario, one imported diet ingredient was replaced with a diet ingredient produced in the Netherlands. Finally, we formulated a scenario in which several ingredients, that individually resulted in the lowest mean change in ecological impact along the organic egg production chain, were replaced simultaneously.

5.2. Materials and methods

5.2.1. Ecological impact

Ecological impact of egg production was calculated by means of LCA, which is an integral method that evaluates ecological impact resulting from the entire life cycle of a product (Guinée et al., 2002). An LCA allows evaluation of different ecological issues simultaneously and comparison of products originating from different production systems.

An LCA starts with the definition of the boundary of the production system (Fig. 5.1), and the corresponding functional unit. The functional unit, the main product of interest of the system in quantitative terms, was defined as one kg of eggs leaving the farm gate. The LCA relates the ecological impact of each process in the production system to the functional unit. For each process in the production system, a life cycle inventory was modelled, including inputs, outputs, and substances that contributed to the ecological impacts. Processes included in this LCA of organic egg production were production of diet and litter (i.e. sand and organic wheat straw used as bedding material), hatching, rearing hen husbandry, laying hen husbandry, and transport (Fig. 5.1). Some of these processes resulted in multiple outputs: laying hen husbandry, for example, yields eggs and slaughter hens, oil pressing of soy beans yields oil and soy bean expeller and wheat cultivation may also yield straw. To divide ecological impact among multiple outputs we used economic allocation. Economic allocation is a method to divide the total ecological impact of a production chain, between multiple outputs based on the economic value of each output. No ecological impact was assigned to hen manure, because we assumed manure to have an economic value of zero (Dekker et al, 2011b).

We evaluated egg production based on eight ecological indicators, that were all expressed per kg of egg: i.e. global warming potential, energy use, land occupation, acidification potential, N deficit, P deficit, N surplus, and P surplus. Substances that contributed to each of these indicators were summed up and expressed in one common unit based on equivalence factors (Dekker et al., 2011b). For global warming potential, for example, we computed emissions of CO_2, CH_4, and N_2O from processes in the entire egg production chain: CO_2 emission from combustion of fossil fuel, CH_4 and N_2O emission from laying and rearing hen manure (in hen house and storage) and applied manure during cultivation of diet ingredients. Global warming potential was the sum of these three greenhouse gases, based on

IPCC (2006) equivalence factors in terms of CO_2-equivalents (1 for CO_2, 25 for CH_4, and 298 for N_2O).

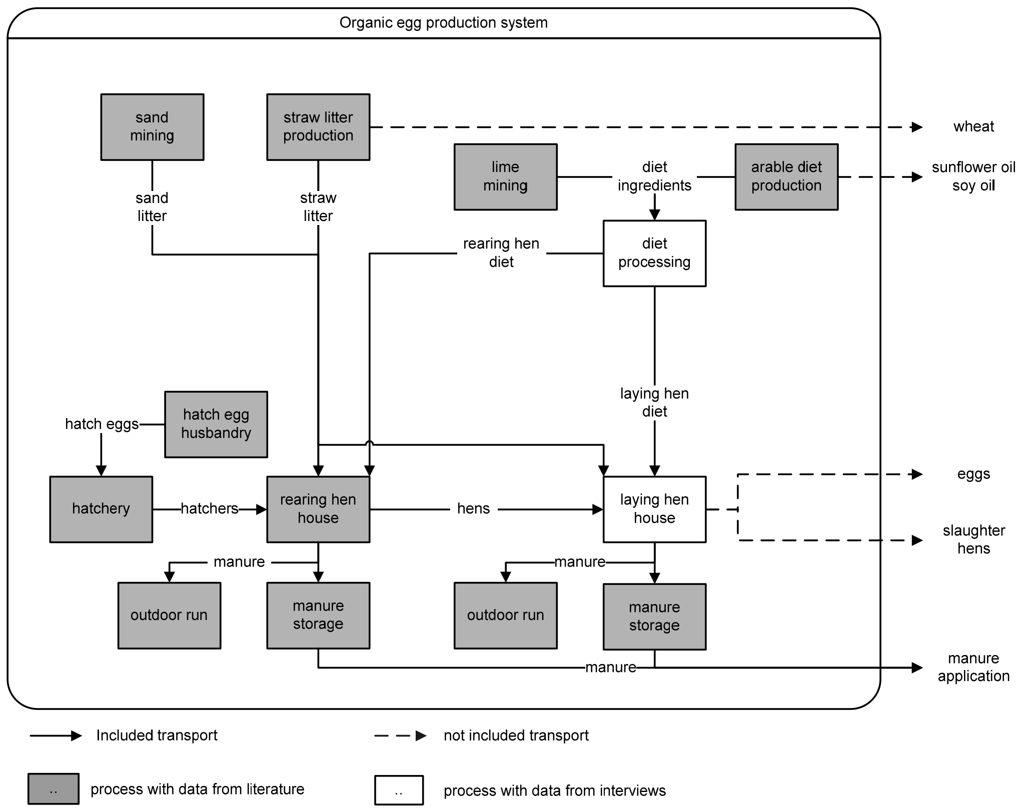

Figure 5.1. System boundary of the life cycle assessment of organic egg production.

Ecological indicators, their units, contributing substances, and equivalence factors were included in this LCA conform to Dekker et al. (2011b). The ecological indicators N surplus, P surplus, N deficit and P deficit were derived from a N and P balance (see section 5.2.4). The N and P surplus and deficit were computed separately, because a surplus refers to the ecological issue eutrophication, whereas a deficit refers to the issue of soil depletion. Eutrophication and soil depletion are different ecological issues, which cannot be summed along the production chain. Soil eutrophication and depletion, however, can occur simultaneously in the production chain, because diet ingredients are produced in several locations.

5.2.2. Definition of composition of current and scenario diets

We compared LCA results of current Dutch organic egg production (i.e. B, the base diet) with several scenarios. In each scenario, one imported diet ingredient was replaced with a nutritionally comparable diet ingredient produced in the Netherlands. Finally, we formulated a scenario (MU) with diet ingredients from B and the scenarios that individually resulted in the lowest overall ecological impact along the organic egg production chain. We included differences between production chains in cultivation (i.e. field operation, manure application and yield), transport, feed intake, egg production and N excretion in the LCAs.

Diet ingredients were replaced on a dry matter (DM) basis. Diet composition of B and scenarios are in Table 5.1. Choice of regional ingredients was based on: availability of data; successful cultivation of the ingredient in the Netherlands; knowledge about content of crude protein, methionine, lysine, and apparent metabolizable energy (AMEn) of the ingredient (Table 5.2); and a content comparable with the imported diet ingredient that was replaced.

Diet composition assumed for B averaged compositions reported (anonymously in interviews) by feed industries from 2006 through 2008. The diet in B contained maize from Italy, wheat from the Ukraine, soy bean expeller from Brazil, equal shares of lime from Germany and Belgium, sunflower seed expeller from the Ukraine, peas from Germany, potato protein from the Netherlands and maizeglutenmeal from Italy. The diet in B contained AMEn at 12.9 MJ kg^{-1} DM, lysine at 7.67 g kg^{-1} DM and methionine at 2.94 g kg^{-1} DM. Maize from Italy was replaced with Dutch maize (scenario M1) or Dutch corn cob mix (scenario M2). Wheat from the Ukraine was replaced with Dutch wheat (scenario W1), Dutch triticale (scenario W2), Dutch barley (scenario W3) or Dutch oats grain (scenario W4). Brazilian soy bean expeller and German peas were replaced with Dutch rapeseed expeller (scenario S1 for replacement of soy beans and scenario P1 for replacement of peas), Dutch horse beans (scenarios S2 and P2), Dutch lupines (scenarios S3 and P3) or Dutch alfalfa silage (scenarios S4 and P4). Ukrainian sunflower seed expeller was replaced with Dutch rapeseed expeller (scenario SE1) and Dutch alfalfa silage (scenario SE2). Italian maizeglutenmeal was replaced with Dutch alfalfa silage (scenario MG). Scenario MU included maize from Italy, lime from Germany and Belgium, Italian maizeglutenmeal, Dutch triticale, and Dutch rapeseed expeller.

5.2.3. Nutritional content and feed efficiency of the diets

Nutritional content and feed efficiency of each diet are in Table 5.2. Content of N, AMEn, and digestible methionine of each diet was calculated based on the proportion of diet ingredients and the individual nutritional composition of each ingredient (CVB, 2008). Feed intake of a hen was determined by the AMEn requirement of the hen (NRC, 1994). The AMEn requirement of the organic hen (1.29 MJ hen^{-1} d^{-1}) was calculated by multiplying feed intake (Dekker et al., 2011b) with AMEn content of the current diet (B). The AMEn requirement of the hens in each scenario was assumed similar to B. Feed intake in each scenario, therefore, resulted from AMEn requirement in B divided by the AMEn content of the diet. We calculated egg mass (EM_i in g hen^{-1} d^{-1}) for each diet (i) as (Van Krimpen et al., 2011):

$$EM_i = -0.5 - 1.65 * G + 0.121 * E + 82 * M_i - 0.81 * T \quad (1)$$

where, EM_i is the egg mass produced (g hen^{-1} d^{-1}), G is the growth rate (i.e. 1.06 g hen^{-1} d^{-1}), E is the AMEn intake in kCal (i.e. 309 kCal hen^{-1} d^{-1} or 1.29 MJ hen^{-1} d^{-1}), M_i is the digestible methionine intake from diet i (mg hen^{-1} d^{-1}) and T is the environmental temperature (i.e. 20 ºC). Equation 1 shows that we assumed that the only variable affecting egg mass of B and scenarios was M_i.

5.2.4. Definition of egg production chain

The processes: rearing hen husbandry and feed production of rearing hens, production of litter, hatching, transport of rearing hens, transport of laying hen manure, and transport of feed from the feed factory to the farm were assumed equal for B and all 18 scenarios. Ecological impact of these processes were equal to organic multi-tiered egg production of Dekker et al. (2011b).

In the LCA's of scenarios, we replaced the processes: cultivation, processing and transport of a currently used imported diet ingredient with processes of an alternative Dutch diet ingredient. This replacement of processes affected ecological impact of production of the diet. For each scenario we, therefore, modeled changes in laying hen husbandry, i.e. changes in feed intake, N content of the diet, and egg production. These changes affected the ecological impact of laying hen husbandry, because they influenced the N and P mass balance, i.e. excretion of N and P per hen per day, emissions of NH_3, N_2O and nitrogen oxides (NO_x) from laying hen manure and the total amount of N and P lost to the outdoor run (i.e. calculated as a share of the total excretion of N and P) (Dekker et al., 2011b). Moreover, exchange of diet ingredients affected the ecological

Table 5.1 Composition of current (B) and scenario diets in g kg^{-1} dry matter.

	B	M1	M2	W1	W2	W3	W4	S1	S2	S3	S4	SE1	SE2	P1	P2	P3	P4	MG	MU
Maize Italy	390	-	-	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390	390
Wheat Ukraine	269	269	269	-	-	-	-	269	269	269	269	269	269	269	269	269	269	269	-
Soy bean expeller Brazil	103	103	103	103	103	103	103	-	-	-	-	103	103	103	103	103	103	103	-
Lime Germany/ Belgium	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124
Sunflower expeller Ukraine	43	43	43	43	43	43	43	43	43	43	43	-	-	43	43	43	43	43	-
Peas Germany	30	30	30	30	30	30	30	30	30	30	30	30	30	-	-	-	-	30	-
Potato protein Netherlands	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Maizeglutenmeal Italy	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	-	21
Maize Netherlands	-	390	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corn cob mix Netherlands	-	-	390	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wheat Netherlands	-	-	-	269	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triticale Netherlands	-	-	-	-	269	-	-	-	-	-	-	-	-	-	-	-	-	-	269

Barley Netherlands	-	-	-	-	-	269	-	-	-	-	-	-	-	-	-	-	-	-	-
Oats grain Netherlands	-	-	-	-	-	-	269	-	-	-	-	-	-	-	-	-	-	-	-
Rapeseed expeller Netherlands	-	-	-	-	-	-	-	103	-	-	-	43	-	30	-	-	-	-	175
Horse beans Netherlands	-	-	-	-	-	-	-	-	103	-	-	-	-	-	30	-	-	-	-
Lupines Netherlands	-	-	-	-	-	-	-	-	-	103	-	-	-	-	-	30	-	-	-
Alfalfa silage Netherlands	-	-	-	-	-	-	-	-	-	-	103	-	43	-	-	-	30	21	-

Table 5.2 Content of dry matter, crude protein (CP), digestible methionine (MET), digestible lysine (LYS), nitrogen (N) and apparent metabolizable energy (AMEn) of current and scenario diets and corresponding feed efficiency, i.e. feed intake, egg production and feed conversion.

Scenario[a]	Content of						Feed efficiency		
	DM	CP	MET	LYS	N	AMEn	Feed intake	Egg production	Feed conversion[b]
	(g DM kg^{-1})	(g kg^{-1} DM)				(MJ kg^{-1} DM)	(g DM hen^{-1} d^{-1})	(g hen^{-1} d^{-1})	(kg DM kg^{-1})
B	895	174	2.94	7.67	27.8	12.9	101	43.5	2.32
M1	895	174	2.94	7.67	27.8	12.9	101	43.5	2.32
M2	772	175	2.64	7.26	27.9	12.7	102	41.3	2.48
W1	895	174	2.94	7.67	27.8	12.9	101	43.5	2.32
W2	891	174	2.98	7.82	27.9	12.7	102	44.1	2.32
W3	889	172	2.99	7.74	27.5	12.6	103	44.4	2.32
W4	895	171	2.82	7.27	27.4	12.3	105	43.5	2.42
S1	895	160	2.84	6.87	25.7	12.6	103	43.0	2.39
S2	892	153	2.75	6.95	24.5	12.8	101	41.9	2.41
S3	895	166	2.72	6.92	26.6	12.6	103	42.2	2.45
S4	795	143	2.62	6.26	22.9	12.0	109	42.4	2.56
SE1	895	163	2.75	7.03	26.1	12.8	102	42.1	2.42
SE2	872	160	2.71	6.90	25.6	12.6	103	42.0	2.45

P1	896	177	2.96	7.65	28.3	12.8	102	43.8	2.32
2	895	175	2.94	7.67	28.0	12.8	101	43.5	2.33
P3	895	179	2.93	7.66	28.6	12.8	102	43.6	2.34
P4	864	172	2.90	7.47	27.5	12.6	103	43.7	2.36
MG	872	163	2.70	7.50	26.1	12.6	103	42.0	2.46
MU	892	167	2.92	7.18	26.7	12.4	105	44.2	2.37

[a] For abbreviation of scenarios see Section 5.2.2.

[b] kg DM feed kg^{-1} egg.

impact through changes in the amount of feed needed to produce 1 kg of eggs. All arable ingredients and lime present in the laying hen diet were included in the LCA's. Ecological impact of vitamins and minerals in the diet was excluded.

5.2.5. Impact related to cultivation and processing of diet ingredients

We computed ecological impacts of cultivation, transport and processing for each diet ingredient (Dekker et al., 2011b). For cultivation of each diet ingredient we included ecological impact related to production of seed. We, moreover, included field emissions of NH_3, N_2O and NO_x from fertilizers and crop residues, N and P surpluses and deficits in the soil after cultivation and land use for cultivation. For field operation we included ecological impact for production of machinery, energy use and emissions of CO_2, sulfur oxide (SO_x) and NO_x from fuel combustion. Field operation included seed-bed preparation, sowing and planting, harrowing, irrigation, harvesting, drying, haying and baling.

Ecological impact of sown seeds was assumed equal to the seed yield grown from the seed. Ecological impact of field operation, irrigation, maize and grain drying, and lime were based on Ecoinvent (2007). Data on the amount of seed, slurry, solid manure, amount and type of field operation, amount and price of main yield, and co yield were based on different literature sources (Borm et al., 2005; BUWAL 250, 1996 ; CVB, 2008; Ecoinvent, 2007; FAO, 2002; FAO, 2005; KWIN-AGV, 2009; Prins, 2007).

For each ingredient, the N and P surplus or deficit was computed as the N and P input to the field minus the N and P output from the field. Field inputs of N and P were N and P in manure, N deposition, N fixation, and N and P in seed, whereas field outputs were N and P in main yield and co yield and N in field emissions of NH_3, N_2O and NO_x. We assumed a content of 4.4 g N kg^{-1} and 0.7 g P kg^{-1} for dairy slurry, and a content of 6.4 g N kg^{-1} and 1.8 g P kg^{-1} for dairy solid manure (KWIN-V, 2007). Content of N and P of seeds, main yield and co yield were available from CVB (2008) and Prins (2007). Deposition of N was assumed to be 30.5 kg ha^{-1} (De Ruiter et al., 2006) in the Netherlands and 15.4 kg ha^{-1} (IPCC, 2006) in other countries. Emission of NH_3-N was computed as a percentage of applied manure N (IPCC, 2006). For the Netherlands, percentage of emitted NH_3-N was 13% (Van der Hoek, 2002) and for outside the Netherlands was 20% (IPCC, 2006), because in the Netherlands immediate incorporation of manure at application in the soil is obligatory (Anon., 1997). Direct emissions of N_2O-N from crop fields were computed as 0.75% of N in crop residues and as 1% of N in manure (IPCC, 2006), whereas direct emissions of NO_x-N were computed as 21% of direct emission of N_2O-N (Ecoinvent, 2007). Indirect emissions of N_2O-N were computed as 1% of emission of NH_3-N and as 0.75% of the N surplus (IPCC, 2006).

Ecological impact was economically allocated (see section 5.2.1) between diet ingredients and co products: soy beans, rapeseed, and sunflower seed resulted in oil and expeller, and wheat, triticale, barley, and oats resulted in grain and straw. Economic allocation percentages of co products are in Table 5.3. The life cycle inventory of processing of soy beans, rapeseed, and sunflower seed into oil and expeller by cold press extraction was based on Ecoinvent (2007). The life cycle inventory of processing of potato protein and maizeglutenmeal was based on BUWAL 250 (1996).

5.2.6. Transport of feed ingredients

For transport over land and water we included ecological impact related to production of transporters and infrastructure, energy and emissions of CO_2, SO_x and NO_x from fuel combustion (Ecoinvent, 2007). Transport distances over land and water of imported diet ingredients were based on interviews with organic feed companies and are in Table 5.3. For all Dutch ingredients, except for potato protein and rape seed expeller, we assumed a transport distance of 100 km over land from the field to the feed factory. Distance over land for potato protein and rape seed expeller was assumed to be 100 km from the field to the processing factory and 100 km from the processing factory to the feed factory.

5.3. Results and Discussion

5.3.1. Replacement of Italian maize

Compared with Italian maize in B, production of Dutch maize in scenario M1 had a lower total input of manure (slurry and solid manure), a lower yield, more drying, and a shorter transport distance (Table 5.3). These differences resulted in a decrease of energy use (98%), acidification potential (96%), N deficit (72%), but an increase in land occupation (102%), and P deficit (163%) of M1 compared with B (Table 5.4). Global warming potential, N surplus and P surplus changed less than 1%. Energy use of M1 reduced only 2% compared with B, because energy use for transport of Dutch maize was lower in scenario M1 (0.27 MJ kg^{-1} egg) than in B (1.20 MJ kg^{-1} egg), but energy use for drying of maize was higher in scenario M1 (1.69 MJ kg^{-1} egg) than in B (0.82 MJ kg^{-1} egg). Energy use for drying in scenario M1 was higher than B, because moisture content of Dutch yielded

Table 5.3 Inputs and outputs, field operation, transport, and economic allocation percentages for straw and oil of diet ingredients per hectare and per cultivation round, produced in Italy (IT), Ukraine (UKR), Brazil (BR), Germany (GER) and the Netherlands (NL).

Description (unit)	Maize IT	Wheat UKR	Soy bean BR	Sunflower seed UKR	Peas GER	Potatoes NL	Maize NL	Corn cob mix NL	Wheat NL	Triticale NL	Barley NL	Oats grain NL	Rapeseed NL	Horse beans NL	Lupines NL	Alfalfa silage NL
Inputs and outputs																
Seed (kg ha^{-1})	25	200	70	3	275	3000	25	25	160	180	140	150	5	155	145	8
Slurry (m^3 ha^{-1})	9.5	-	-	-	26.5	25.0	15.0	15.0	-	20.0	15.0	15.0	34.0	-	-	-
Solid manure (t ha^{-1})	10.0	4.0	-	-	7.0	30.0	-	-	20.0	-	-	-	-	-	-	-
Main yield (t ha^{-1})	9.7	2.5	2.3	1.1	3.0	29	8.4	11.6	5.0	4.5	4.3	5.0	2.5	4.5	3.5	29.8
Straw yield (t ha^{-1})	-	-	-	-	-	-	-	-	3.0	2.5	2.8	3.0	2.0	-	-	-

Field operation																
Seed-bed preparation ($nr\ ha^{-1}$)	1	1	3	1	1	4	1	1	1	1	1	1	1	1	1	0.33
Sowing and planting ($nr\ ha^{-1}$)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.33
Harrowing ($nr\ ha^{-1}$)	2	1	1	1	2	1	2	2	2	2	2	2	2	2	2	1
Irrigation ($nr\ ha^{-1}$)	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Harvesting ($nr\ ha^{-1}$)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.5
Drying (kg water ha^{-1})	873	-	-	147	46	-	3201	-	75	67.5	63.8	75	37.5	67.5	52.5	-
Haying and baling ($nr\ ha^{-1}$)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5
Transport																
Distance over land (km)	1209	489	234	6544	300	200	100	100	100	100	100	100	200	100	100	100
Distance over water (km)	90	6544	9929	589	-	-	-	-	-	-	-	-	-	-	-	-
Allocation to grain (%)	-	-	-	-	-	-	-	-	89.6	90.0	87.2	88.0	-	-	-	-
Allocation to expeller (%)	-	-	73.9	54.4	-	-	-	-	-	-	-	-	25.1	-	-	-

Table 5.4 (a) Ecological impacts (% relative to B) of current organic egg production (B) and scenarios of organic egg production, i.e.: global warming potential, energy use, land occupation, acidification potential, N deficit, P deficit, N surplus, and P surplus. Mean change in ecological impact (of eight ecological impacts) relative to B (%).

	Global warming potential ($g\ CO_2$ eq.[b] kg^{-1})[c]		Energy use ($MJ\ kg^{-1}$)[c]		Land occupation ($m^2\ y\ kg^{-1}$)[c]		Acidification potential ($g\ SO_2$ eq.[b] kg^{-1})[c]	
B[a]	2,291	(100)	18.2	(100)	7.15	(100)	43.0	(100)
M1[a]	2,287	(100)	17.9	(98)	7.32	(102)	41.2	(96)
M2[a]	2,395	(105)	18.4	(101)	6.84	(96)	44.9	(104)
W1[a]	2,197	(96)	16.1	(89)	5.40	(75)	42.6	(99)
W2[a]	2,159	(94)	16.0	(88)	5.56	(78)	41.5	(96)
W3[a]	2,133	(93)	16.0	(88)	5.59	(78)	40.3	(94)
W4[a]	2,188	(95)	16.4	(90)	5.54	(77)	41.5	(96)
S1[a]	2,232	(97)	17.4	(96)	7.24	(101)	43.0	(100)
S2[a]	2,206	(96)	17.6	(97)	7.56	(106)	40.3	(94)
S3[a]	2,321	(101)	17.9	(98)	7.81	(109)	43.4	(101)
S4[a]	2,261	(99)	18.7	(103)	7.44	(104)	41.0	(95)
SE1[a]	2,312	(101)	18.2	(100)	6.93	(97)	43.7	(102)
SE2[a]	2,311	(101)	18.2	(100)	6.77	(95)	43.3	(101)

P1[a]	2,285	(100)	18.0	(99)	6.97	(97)	43.7	(102)
P2[a]	2,275	(99)	18.0	(99)	7.05	(99)	42.9	(100)
P3[a]	2,307	(101)	18.1	(100)	7.12	(100)	43.8	(102)
P4[a]	2,291	(100)	18.3	(101)	7.01	(98)	43.1	(100)
MG[a]	2,362	(103)	19.0	(105)	7.53	(105)	43.8	(102)
MU[a]	2,075	(91)	14.4	(79)	4.89	(68)	42.8	(99)

[a] For abbreviations of scenarios see section 5.2.2

[b] eq. = equivalent

[c] kg^{-1} = per kg egg produced

Table 5.4 (b) Ecological impacts (% relative to B) of current organic egg production (B) and scenarios of organic egg production, i.e.: global warming potential, energy use, land occupation, acidification potential, N deficit, P deficit, N surplus, and P surplus. Mean change in ecological impact (of eight ecological impacts) relative to B (%).

	N deficit ($g\ N\ kg^{-1}$)[c]		P deficit ($g\ P\ kg^{-1}$)[c]		N surplus ($g\ N\ kg^{-1}$)[c]		P surplus ($g\ P\ kg^{-1}$)[c]		Mean change (%)
B[a]	5.22	(100)	2.02	(100)	25.4	(100)	2.10	(100)	100.0
M1[a]	3.78	(72)	3.30	(163)	25.4	(100)	2.10	(100)	103.9
M2[a]	2.13	(41)	1.94	(96)	32.4	(127)	3.91	(186)	107.0
W1[a]	4.99	(96)	2.02	(100)	31.8	(125)	4.52	(215)	111.9
W2[a]	4.96	(95)	2.30	(114)	28.7	(113)	2.08	(99)	97.1
W3[a]	4.96	(95)	2.97	(147)	26.8	(105)	2.09	(100)	100.0
W4[a]	5.16	(99)	3.30	(163)	25.9	(102)	2.16	(103)	103.1
S1[a]	5.34	(102)	0.86	(43)	24.6	(96)	2.41	(115)	93.8
S2[a]	5.42	(104)	2.37	(117)	26.6	(104)	2.19	(104)	102.8
S3[a]	5.47	(105)	1.70	(84)	28.8	(113)	2.21	(105)	102.0
S4[a]	5.67	(109)	1.69	(84)	23.0	(90)	2.42	(115)	99.9
SE1[a]	4.79	(92)	1.78	(88)	27.3	(107)	2.30	(109)	99.5
SE2[a]	4.76	(91)	2.07	(102)	26.7	(105)	2.21	(105)	100.0

P1[a]	5.20	(100)	2.02	(100)	22.0	(86)	1.34	(64)	93.5
P2[a]	5.22	(100)	2.44	(121)	22.5	(88)	1.27	(60)	95.8
P3[a]	5.23	(100)	2.26	(112)	23.1	(91)	1.27	(61)	95.9
P4[a]	5.28	(101)	2.27	(112)	21.4	(84)	1.31	(62)	94.8
MG[a]	5.33	(102)	2.28	(113)	26.6	(105)	2.23	(106)	105.1
MU[a]	4.44	(85)	0.83	(41)	25.8	(101)	1.70	(81)	80.6

[a] For abbreviations of scenarios see section 5.2.2
[b] eq. = equivalent
[c] kg^{-1} = per kg egg produced

maize was higher than of Italian yielded maize. Scenario M1 versus B demonstrated that reduction of energy use per kg egg should be approached from an integral perspective, because several processes in the production chain contributed to total energy use per kg egg.

Compared with Italian maize in B, production of Dutch corn cob maize in scenario M2 had a lower total input of manure, higher yield, no drying and a shorter transport distance (Table 5.3). Methionine content of the diet in scenario M2 was lower (2.64 g kg^{-1} DM) than for the diet in B (2.94 g kg^{-1} DM), resulting in a lower egg production per hen per day for scenario M2 (41.3 g hen^{-1} d^{-1}) than for B (43.5 g hen^{-1} d^{-1}), whereas feed intake in scenario M2 (102 g DM hen^{-1} d^{-1}) was slightly higher than in scenario B (101 g DM hen^{-1} d^{-1}) (Table 5.2). Differences in egg production and feed intake resulted in a higher feed conversion in scenario M2 (2.48 kg DM kg^{-1}) than in B (2.32 kg DM kg^{-1}) (Table 5.2). The higher feed conversion of M2 had an increasing effect on the ecological impact per kg egg of scenario M2 compared with B, whereas production parameters of Dutch corn cob mix and a shorter transport distance had a reducing effect. Compared with B scenario M2 had a higher global warming potential (105%), energy use (101%), acidification potential (104%), N surplus (127%), and P surplus (186%), but a lower land occupation (96%), N deficit (41%), and P deficit (96%) (Table 5.4).

Italian maize was the main ingredient of the diet. Production and transport of Italian maize, therefore, contributed substantially to global warming potential (10.9%), energy use (16.6%), land occupation (14.9%), acidification potential (11.6%), P deficit (9.9%), and N deficit (58.8%) of B. Replacement of Italian maize with Dutch maize or Dutch corn cob maize, however, did increased overall ecological impact of organic eggs. Other options to reduce ecological impact of production of organic maize should be explored, especially for N deficit, because of the large contribution of maize to N deficit of organic eggs. Maize is a crop with a high yield compared with other diet ingredients, but maize also requires a large amount of manure applied per hectare (Table 5.3). An applied amount of manure that exactly fits the required N and P of the crop and results in a high yield, therefore, may be an option to reduce the ecological impact.

5.3.2. Replacement of Ukrainian wheat

Compared with production of Ukrainian wheat (B) scenarios with Dutch grain (W1, W2, W3 and W4) had a higher yield resulting from a higher applied amount of manure per hectare. Dutch grain scenarios also had a shorter transport distance (Table 5.3). Scenario W4, with Dutch oats grain, had a lower AMEn content (12.3 MJ kg^{-1} DM) than B (12.9 MJ kg^{-1} DM), resulting in a higher feed intake per hen per day for W4 (105 g DM hen^{-1} d^{-1}) than for B (101 g DM hen^{-1} d^{-1}) and a higher feed conversion (Table 5.2). This higher feed conversion had an increasing effect on ecological impact of W4 compared with B, whereas a high yield and a shorter transport distance of Dutch grains had a reducing effect on the ecological impact. Compared with B scenarios with Dutch grains resulted in a lower ecological impact for global warming potential (93% to 96%), energy use (88% to 90%), land occupation (75% to 78%) and acidification potential (94% to 99%) (Table 5.4).

In scenarios W2, W3, and W4 slurry manure was applied, whereas in scenario W1 solid manure was applied (Table 5.3). The P content of slurry manure was too low compared with the N content required for grain crops, resulting in a higher N surplus (102% to 113%) and P deficit (114% to 163%) of scenario W2, W3 and W4 compared with B (Table 5.4). The N deficit of all Dutch grain scenarios was lower than B (96% to 99%), because in the scenarios more manure was applied. Scenario W1 was over fertilized with solid manure, resulting in a higher N surplus (125%) and P surplus (215%) compared with B. Triticale was selected as an ingredient for scenario MU, because W2 had a lower mean ecological impact (97.1%) than B (100.0%), W1 (111.9%), W3 (100.0%), and W4 (103.1%).

5.3.3. Replacement of Brazilian soy bean expeller

A higher yield and a shorter transport distance of scenarios S1, S2, S3, and S4 compared with B had a reducing effect on the ecological impact. A higher feed conversion of S1 (2.39 kg DM kg^{-1}), S2 (2.41 kg DM kg^{-1}), S3 (2.45 kg DM kg^{-1}) and S4 (2.56 kg DM kg^{-1}) compared with B (2.32 kg DM kg^{-1}) (Table 5.2), however, had an increasing effect on the ecological impact (Table 5.4). In scenario S1, soy bean expeller was replaced with rapeseed expeller. Expeller is a co product of seed oil production. In scenarios S2, S3 and S4 soy bean expeller was replaced with whole arable products, i.e. horse beans (S2), lupines (S3) and alfalfa (S4). Economic allocation of soy bean expeller (73.9%), however was higher than of rapeseed expeller (25.1%), resulting in a higher fraction of the ecological impact of cultivation of seed being allocated to soy bean expeller than to rapeseed expeller.

Replacement of soy bean expeller resulted in a higher ecological impact for land occupation (101% to 109%), N deficit (102% to 109%) and P surplus (104% to 115%) (Table 5.4). Rapeseed expeller was selected to replace soy bean expeller in scenario MU, because S1 had a lower mean ecological impact (93.8%) than B (100.0%), S2 (102.8%), S3 (102.0%), and S4 (99.9%). Compared with B scenario S1 had lower global warming potential (97%), energy use (96%), P deficit (43%) and N surplus (96%), equal acidification potential, and higher land occupation (101%), N deficit (102%) and P surplus (115%) (Table 5.4). Scenario S1 resulted in a reduction of the P deficit, because in contrast to soy beans expeller (B), horse beans (S2), lupines (S3) and alfalfa silage (S4) manure was applied to rapeseed expeller. The N surplus of S1, however, increased for replacement of soy bean expeller with rapeseed expeller, because N-P ratio of the applied slurry did not fit the required N-P ratio of cultivation of rapeseed.

5.3.4. Replacement of Ukrainian sunflower seed expeller

Differences in ecological impact of replacement of Ukrainian sunflower seed expeller with Dutch rapeseed expeller were caused by the same principles as replacement of Brazilian soy bean expeller with Dutch rapeseed expeller (see paragraph 3.3). Economic allocation of sunflower seed expeller (54.4%), however was higher than of rapeseed expeller (25.1%), resulting in a higher fraction of the ecological impact of cultivation of seed being allocated to sunflower seed expeller than to rapeseed expeller. Rapeseed expeller was selected to replace sunflower seed expeller in scenario MU, because SE1 (99.5%) had a lower mean ecological impact than B (100.0%), and SE2 (100.0%).

5.3.5. Replacement of German peas

Feed conversion of scenarios replacing peas (P1 to P4) (2.32 to 2.36 kg DM kg^{-1}) was lower than of scenarios replacing soy bean expeller (S1 to S4) and sunflower seed expeller (SE1 and SE2) (2.39 to 2.56 kg DM kg^{-1}), but in the same range as B (2.32 kg DM kg^{-1}) (Table 5.2). In scenario P1 whole peas were replaced with economical allocated rapeseed expeller. Replacement of peas hardly affected global warming potential, energy use, land occupation, acidification potential and N deficit (97% to 102%) (Table 5.4). Replacement of peas, however, reduced N surplus (84% to 91%) and P surplus (60% to 64%). In scenario P1 with rapeseed expeller P deficit was equal to B, whereas in scenarios P2, P3 and P4, P deficit was higher than B (112% to 121%), because manure was applied to rapeseed (P1), but not to horse beans (P2), lupines (P3) and alfalfa (P4) (Table 5.3). The reason no manure was applied to horse beans, lupines, and alfalfa is that they fix N from the air. Cultivation of crops that fix N from the air without application of manure, however, inevitably results in a P deficit. Rapeseed expeller was selected to replace peas in scenario MU, because P1 had a lower mean ecological impact (93.5%) than B (100.0%), P2 (95.8%), P3 (95.9%), and P4 (94.8%).

5.3.6. Replacement of maizeglutenmeal

Replacement of maizeglutenmeal (B) with alfalfa silage (MG) increased feed conversion from 2.32 to 2.46 kg DM kg^{-1} (Table 5.2). This increase of feed conversion was the main reason, that replacement of maizeglutenmeal (B) with alfalfa silage (MG) increased all ecological impacts (102% to 113%) compared with B (Table 5.4).

5.3.7. Replacement of multiple concentrate ingredients

In the multiple replacement scenario (MU) diet ingredients were replaced based on the lowest mean ecological impact. We replaced Ukrainian wheat with Dutch triticale, and we replaced Brazilian soy bean expeller, Ukrainian sunflower seed expeller and German peas with rapeseed expeller. Compared with B ecological impact of scenario MU decreased for global warming potential (91%), energy use (79%), land occupation (68%), acidification potential (99%), N deficit (85%), P deficit (41%) and P surplus (81%) (Table 5.4), but increased for N surplus (101%). Replacement of several ingredients simultaneously resulted in a lower mean ecological impact (80.6%) than replacement of single ingredients (93.5% to 111.9%). Moreover, scenario MU resulted in a more integral reduction of the ecological impact, because in contrast to the single scenarios almost all ecological impacts were reduced simultaneously. The low ecological impact of MU was explained by: 1) a reduction of the transport distance of 44.4% of the diet ingredients, 2) replacement of current used crops with crops that have a higher yield in combination with a balanced applied amount of manure, and 3) use of expellers instead of whole ingredients, despite a relative small increase of feed conversion (from 2.32 kg feed kg^{-1} egg for B to 2.37 kg feed kg^{-1} egg for MU).

5.3.8. General discussion

This research identified the potential of several diet ingredients with different origins to reduce the ecological impact of organic eggs. Moreover, this research identified four major characteristics of diet ingredients that affected ecological impact of organic eggs (low feed conversion, short transport distance, high yield in combination with a balanced amount of manure and use of expeller rather than whole ingredients). Optimizing the integral ecological impact of livestock products by means of linear programming of diets with a focus on these four characteristics may be an effective approach for further research. Optimizing for all ecological impacts simultaneously is essential to avoid trade-offs between ecological impacts. We discuss interactions that became apparent in this research.

First, although no correlation was found between ecological impact and change in feed conversion (r^2 = 0.05), the feed conversion of the scenarios with the lowest mean ecological impact (W2, S1, P1, MU) (Table 5.4) was lower than feed conversion of B (Table 5.2). To reduce the integral ecological impact of a diet, we, therefore, should aim at a low feed conversion in combination with a low ecological impact of production of diet ingredients.

Second, acidification potential of organic eggs was mainly caused by emission of NH_3 from the laying hen house (48% in B). An increase of the N excretion per hen per round (variation between 664 g N for scenario S4 and 827 g N for scenario P3), induced an increase of the NH_3 emission from the hen house per hen per round (145 g for S4 and 180 g for P3), but also increased egg mass per hen per round (16.7 kg for S4 and 17.4 kg for P3), because amino acid (i.e. methionine) intake was higher. Per kg egg produced, therefore, acidification potential (41.0 g SO_2 eq. kg^{-1} egg for S4 and 43.8 g SO_2 eq. kg^{-1} egg for P3) resulting from the hen house was hardly affected by changes in N excretion.

Third a shorter transport distance reduced energy use and global warming potential. Local production characteristics, however, also influence energy use, such as energy use for drying of a product and energy use for field operation in relation to yield per hectare. A reduction in energy use resulting from a shorter transport distance may be compensated by an increase in energy use for field operation or drying. Energy use, therefore, must be optimized from a chain perspective.

Fourth, the amount of manure applied and the N-P ratio of manure affected the N and P balance as well as the yield. Crop specific application of manure with an optimal N-P ratio is required to minimize N and P surpluses and deficits per kg diet ingredient and minimize land occupation.

We calculated that current implementation of scenario MU would require 4691 ha of Dutch land occupation. This calculation was based on: total land occupation of MU (4.89 m^2 y kg^{-1} egg) (Table 5.4), share of the MU diet originating from the Netherlands (46.5%) (Table 5.1), number of organic laying hens in the Netherlands in 2010 (1.3 million hens), assumed number of days laying hens stayed on the farm (398 days), assumed number of eggs produced per hen per round (276 hen^{-1} $round^{-1}$), and assumed egg mass (62.7 g) (Dekker et al., 2011b). If MU would be implemented land occupation in the Netherlands allocated to Dutch organic egg production would be 8.7% of total current occupied land for organic agriculture and 0.3% of total current occupied land for agriculture (Bakker, 2011). We, therefore, conclude that regarding land occupation scenario MU is feasible. An option to realize scenario MU, would be to implement legislation that requires that 45% of cultivation of the diet for organic laying hens should originate from within 100 km of laying hen farm. This research did not include effect of change of origin and diet composition on water use, biodiversity, deforestation and carbon sequestration. Moreover, economic and social sustainability were not regarded. These topics should be addressed prior to adoption of new diets.

5.4. Conclusion

Replacement of Ukrainian wheat with Dutch triticale, and replacement of Brazilian soy beans, Italian sunflower seed expeller and German peas with Dutch rapeseed expeller reduced the integral ecological impact compared with current organic egg production. Simultaneous replacement of these ingredients (scenario MU) resulted a lower mean ecological impact (80.6%) than single replacement of these ingredients (93.5% to 111.9%) (Table 5.4). Moreover, simultaneous replacement resulted in a more integral reduction of the ecological impact, because in contrast to the single scenarios almost all ecological impacts were reduced.

Compared with B ecological impact of scenario MU decreased for global warming potential (91%), energy use (79%), land occupation (68%), acidification potential (99%), N deficit (85%), P deficit (41%) and P surplus (81%), but slightly increased for N surplus (101%) (Table 5.4). The low ecological impact of MU was explained by: 1) a reduction of the transport distance of 44.4% of the diet ingredients, 2) replacement of current used crops with crops that have a higher yield in combination with a balanced applied amount of N and P in manure, and 3) use of expeller instead of whole ingredients, despite a relative small increase of feed conversion (from 2.32 kg feed kg^{-1} egg for B to 2.37 kg feed kg^{-1} egg for MU).

Chapter 6

General discussion

6.1. Discussion

The current practice of organic egg production results from a combination of the organic ethical framework, legislation, economy, and available resources and technology. In this thesis, differences in ecological impact between current organic and non-organic egg production systems were shown. Main issues that contribute to the ecological impacts identified were: global warming, energy use, land occupation, fossil P use, acidification, N deficit, P deficit, N surplus, and P surplus. The organic ethical framework of current organic egg production was in this study translated in three specific requirements, i.e. loose hen housing, access to an outdoor run, and prohibited use of external resources. The effect of each requirement on the ecological impact of organic egg production was assessed and options to reduce this impact within the boundaries of the organic ethical framework were evaluated.

Some ecological issues (e.g. water depletion, loss of biodiversity, deforestation, carbon sequestration, and fine dust emissions) were not included in this thesis, either because data on these issues were not available throughout the production chain (i.e. loss of biodiversity and fine dust emissions) or because there is no scientific consensus on the methodology to assess these ecological issues from an integral perspective (i.e. water depletion, loss of biodiversity, deforestation, and carbon sequestration). Moreover, social and economic sustainability were not fully elaborated in this thesis. Improvement of animal welfare, however, is a social aspect and implicitly included in the loose housing systems under review, whereas economic sustainability was addressed in Chapter 2. The conclusions from this thesis, therefore, are not conclusive to answer the question whether organic agriculture is more sustainable than non-organic agriculture. The sustainability assessment performed in this thesis is meant as a tool to identify the strengths and weaknesses of production systems.

In the following sections, we discuss the results for each of the three requirements (i.e. loose hen housing, access to an outdoor run, and prohibited use of external resources) and end with a general conclusion and recommendations regarding the main objective of this thesis: To assess the effect of the organic ethical framework on the integral ecological impact of Dutch organic egg production.

6.1.1. Loose hen housing

The organic ethical framework requires care for the welfare of living beings. This results in the requirement of loose hen housing in organic hen husbandry. In 2007, 85% of the organic laying hens in the Netherlands were kept in single-tiered and 15% in multi-tiered hen houses (Dekker et al., 2009). Non-organic laying hens are housed in battery cages, single-tiered, and multi-tiered hen houses (Anon., 2008; CBS, 2010; PVE, 2010). From 2012 onwards, housing of hens in battery cages is prohibited in the European Union (EC, 1999a). In addition, Dutch farms with over 40,000 hens need to apply best available techniques, such as a housing system that reduces NH_3 emission from 2013 onwards (VROM, 2005). Most organic laying hen farms have less than 40,000 hens and, therefore, do not have to apply best available techniques. In practice only few large organic laying hen farms invested in multi-tiered housing.

In chapter 2 comparison of non-organic battery cage, single-tiered and multi-tiered barn egg production demonstrated the ecological impact of housing, because the other two requirements (i.e. access to an outdoor run and prohibited use of external resources) were not applied in these systems. Table 6.1 shows that the different impacts for the ecological issues studied are 12% to 176% higher for barn egg production than for battery cage egg production, except for P deficit which was equal. This higher impact is mainly explained by a higher feed conversion of loose housed hens (2.33 kg feed kg^{-1} egg) compared with hens in battery cages (1.99 kg feed kg^{-1} egg). A higher feed conversion reduces all ecological impacts per kg egg, because per kg egg more feed is needed and more N is excreted and subsequently emitted as ammonia (NH_3) and nitrous oxide (N_2O) from laying hen husbandry.

A second reason for the higher acidification potential of single-tiered barn egg production compared with battery cage egg production, was that in single-tiered houses faeces is collected as litter on floors and as manure in a pit, and removed after the production round (396 to 406 days), whereas in battery cages all manure is air-dried on manure belts and removed every five days. Removal and drying of manure reduces emissions of NH_3, N_2O and CH_4 from the hen house (Winkel et al., 2009a). In multi-tiered barn egg production acidification potential was intermediate, because not all manure is collected on belts, air-dried and removed weekly from the hen house. Replacing single-tiered with multi-tiered hen houses in organic agriculture, therefore, reduces acidification potential of organic eggs.

In chapter 3 we measured NH_3, N_2O and CH_4 emissions from multi-tiered hen houses in organic laying hen husbandry on three commercial farms. We found that organic laying hen husbandry in multi-tiered hen houses resulted in comparable NH_3 and CH_4 emissions and lower N_2O emissions per hen per year as in non-organic laying hen husbandry. An option to further reduce NH_3 emission was daily removal of manure from the belts. Manure removal interval, however, had no effect on emissions of N_2O and CH_4. We also found that adding more bedding material to the litter may be an effective strategy to reduce N emission from faeces in the litter, because by adding bedding material, dry matter content of litter is increased, which slows down the emission of NH_3.

Table 6.1 Global warming potential (GWP), energy use (EU), land occupation (LO), fossil P use (FPU), acidification potential (AP), N deficit (ND), P deficit (PD), N surplus (NS), and P surplus (PS) per kg egg for non-organic indoor laying hen husbandry in a battery cage, single-tiered (S) and multi-tiered (M) barn housing.

	(unit)[a]	Battery cage	Barn S		Barn M	
GWP	(kg CO_2 eq.[b] kg^{-1})	2.24	2.69	(120%)[c]	2.66	(119%)[c]
EU	(MJ kg^{-1})	20.7	23.2	(112%)[c]	22.5	(109%)[c]
LO	(m^2y kg^{-1})	3.26	3.75	(115%)[c]	3.75	(115%)[c]
FPU	(g P kg^{-1})	11.0	12.7	(115%)[c]	12.7	(115%)[c]
AP	(g SO_2 eq.[b] kg^{-1})	23.0	63.5	(276%)[c]	40.0	(174%)[c]
ND	(g N kg^{-1})	0.3	0.4	(133%)[c]	0.4	(133%)[c]
PD	(g P kg^{-1})	0.2	0.2	(100%)[c]	0.2	(100%)[c]
NS	(g N kg^{-1})	17.4	20.0	(115%)[c]	20.0	(115%)[c]
PS	(g P kg^{-1})	6.7	7.7	(115%)[c]	7.7	(115%)[c]

[a] per kg egg produced
[b] eq. = equivalents
[c] percentage of ecological impact relative to Battery cage

We conclude that the requirement of loose hen housing, currently implicates an increase of the ecological impact, because feed conversion and emission from the hen house in loose hen houses is higher. Housing organic hens in multi-tiered hen houses instead of single-tiered hen houses will reduce acidification potential, but not to the level of battery cages. Loose hen housing, however, will be common practice in the EU from 2012 onwards. This perspective demands development of a loose hen housing system with NH_3 and N_2O emissions that are comparable with battery cages. Moreover, parameters that affect the difference in feed conversion between battery cage and loose hen husbandry, such as a higher body mass and increased freedom of movement of loose housed hens, need to be further explored and, subsequently, used to reduce feed conversion of loose housed laying hens.

6.1.2. Access to an outdoor run

In organic production, laying hens should have access to an outdoor run (EC, 1991; EC, 1999b). This outdoor run offers hens a natural environment that stimulates natural behaviour such as exploration, running, foraging, sunbathing and dust bathing behaviour, and reduces cannibalism and feather pecking (Knierim, 2006). For each laying hen, four m^2 of outdoor run should be available. Excretion of N and P in the outdoor run generally far exceeds uptake by vegetation (Aarnink et al., 2006). Especially in organic agriculture, loss of N and P from manure needs to be minimized, because the use of artificial fertilizers is prohibited and manure is the main source for fertilization of crops.

Comparison of non-organic loose hen housing in a barn and free range egg production system in chapter 2 demonstrated the ecological impact of access to an outdoor run, because the two other requirements (i.e. loose hen housing and prohibited use of external resources) were equal for these systems. Table 6.2 shows that all impacts of the issues studied are 2% to 9% higher for free range egg production than for non-organic barn egg production, except N and P deficit which was equal. This small increase of impact results from a slightly higher feed conversion of hens with access to an outdoor run (2.33 kg feed kg^{-1} egg), than of hens without access to an outdoor run (2.28 kg feed kg^{-1} egg). The difference in feed conversion and ecological impact caused by access to an outdoor run, however, was smaller than differences in ecological impact caused by the other two requirements (i.e. loose hen housing and prohibited use of external resources).

In chapter 4, we determined level and variation of load of N and P in the outdoor run and the total mass of N and P excreted into the outdoor run. Despite the low percentage of hens outside, varying on average from 1.7% to 13% among farms, all outdoor runs were overloaded with N and P near the hen house. Total mass of N and P excreted into the outdoor run varied from 1.7% to 16.1% of total N and 1.4% to 17.5% of total P excretion. Loss of N and P in the outdoor run decreased exponentially with increasing distance from the hen house. The fertilization standard of 170 kg N per year, used for intensive pasture, was exceeded within distances from the hen house varying from 19 to 146 m. In the area close to the hen house, uptake of N and P by vegetation was none, because vegetation was destructed by hens.

Chapter 2 (Table 2.6) shows that N surplus originated for 50% from laying hen husbandry and for 50% from feed production. Figure 2.2 shows that N surplus from laying hen husbandry fully originates from excretion of N in the outdoor run. In chapter 2, we assumed that 4.3% (Figure 2.2) of total N excreted by the hen was excreted in the outdoor run. In chapter 4, however, we found that in practise 1.7% to 16.1% of total N excreted was excreted in the outdoor run. We calculated a worst case scenario, 16.1% of total excreted N is excreted in the outdoor run. In this scenario, laying hen husbandry would be the major contributor to N surplus (79%) for organic egg production. The N surplus of organic egg production in this scenario (5.7 g N kg^{-1} egg), however, remains much lower than N surplus of non-organic egg production (17.4-21.3 g N kg^{-1} egg). Conclusions for P surplus in this scenario were similar to conclusions for N surplus.

Table 6.2 Global warming potential (GWP), energy use (EU), land occupation (LO), fossil P use (FPU), acidification potential (AP), N deficit (ND), P deficit (PD), N surplus (NS), and P surplus (PS) per kg egg for non-organic single-tiered housed (S) hens with (Free range) and without (Barn) access to an outdoor run.

	(unit)[a]	Barn S	Free range S	
GWP	(kg CO_2 eq.[b] kg^{-1})	2.69	2.75	(102%)[c]
EU	(MJ kg^{-1})	23.2	23.8	(103%)[c]
LO	(m^2y kg^{-1})	3.75	4.08	(109%)[c]
FPU	(g P kg^{-1})	12.7	13.0	(102%)[c]
AP	(g SO_2 eq.[b] kg^{-1})	63.5	65.0	(102%)[c]
ND	(g N kg^{-1})	0.4	0.4	(100%)[c]
PD	(g P kg^{-1})	0.2	0.2	(100%)[c]
NS	(g N kg^{-1})	20.0	21.3	(107%)[c]
PS	(g P kg^{-1})	7.7	8.3	(108%)[c]

[a] per kg egg produced
[b] eq. = equivalents
[c] percentage of ecological impact relative to Barn S

The outdoor run is intended to improve laying hen welfare, but in practice only few hens are outside. More intensive use of the outdoor run, therefore, should be stimulated. If use increases, however, ecological impact will also increase. This increase of the ecological impact should be avoided. Moreover, parameters that affect the difference in feed conversion between indoor and outdoor hen husbandry, such as a lower environmental temperature, increased activity, and exposure to pathogens in the outdoor environment, need to be further explored and, subsequently, used to reduce feed conversion of outdoor housed laying hens.

6.1.3. Prohibited use of external resources

In organic agriculture, use of external resources, that may obstruct ecological processes, biodiversity and cycles, should be avoided as much as possible (IFOAM, 2011). Currently prohibited external resources in organic agriculture are: artificial fertilizers, pesticides, herbicides, genetically modified organisms, and moreover only limited use of medication is allowed (EC 1991; EC 1999b). Prohibition of these external resources is expected to reduce the integral ecological impact, because impacts related to production and use of these external resources are avoided. This reduction, however, may be offset by a lower productivity of cultivation of diet ingredients (yield ha^{-1}) and laying hen husbandry (eggs hen^{-1} $year^{-1}$).

Table 6.3 Global warming potential (GWP), energy use (EU), land occupation (LO), fossil P use (FPU), acidification potential (AP), N deficit (ND), P deficit (PD), N surplus (NS), and P surplus (PS) per kg egg of multi-tiered current (C) free range (Chapter 2) and organic egg production (Chapter 2 and 5) and the scenario (MU, Chapter 5) that replaced several imported diet ingredients with Dutch diet ingredients.

		Chapter 2			Chapter 5		
	(unit)[a]	Free range C	Organic C		Organic C	Organic MU	
GWP	(kg CO_2 eq.[b] kg^{-1})	2.74	2.55	(93%)[c]	2.29	2.08	(91%)[d]
EU	(MJ kg^{-1})	23.1	20.3	(88%)[c]	18.4	14.4	(79%)[d]
LO	(m^2y kg^{-1})	4.07	6.75	(166%)[c]	7.15	4.89	(68%)[d]
FPU	(g P kg^{-1})	13.0	2.8	(22%)[c]	-	-	-
AP	(g SO_2 eq.[b] kg^{-1})	41.8	48.1	(115%)[c]	43.0	42.8	(99%)[d]
ND	(g N kg^{-1})	0.4	5.7	(1425%)[c]	5.2	4.4	(85%)[d]
PD	(g P kg^{-1})	0.2	2.0	(1000%)[c]	2.0	0.8	(41%)[d]
NS	(g N kg^{-1})	21.3	2.4	(11%)[c]	25.4	25.8	(101%)[d]
PS	(g P kg^{-1})	8.3	0.7	(8%)[c]	2.1	1.7	(81%)[d]

[a] per kg egg produced.
[b] eq. = equivalents.
[c] percentage of ecological impact relative to Free range C, Chapter 2.
[d] percentage of ecological impact relative to Organic C, Chapter 5.

Comparison of non-organic and organic loose hen housing with access to an outdoor run in chapter 2 demonstrated the ecological impact of prohibited use of external resources, because the two other requirements (i.e. loose hen housing and access to an outdoor run) were equal for both systems. Table 6.3 shows that ecological impact of egg production with prohibited use of external resources (i.e. organic) was lower for global warming potential (93%), energy use (88%), fossil P use (22%), and N (11%) and P surplus (8%), but higher for land occupation (166%), acidification potential (115%), and N (1425%) and P deficit (1000%; non-organic multi-tiered free range was set as 100%) than for egg production without prohibition of external resources (i.e. free range). We found that differences in ecological impact between organic and free range egg production were determined mainly by type and amount of fertilization, and feed conversion.

Replacement of artificial fertilizer with manure reduced global warming potential (i.e. CO_2 emission), energy use, and fossil P depletion, because fossil energy and fossil P required for production of artificial fertilizer was avoided. Replacement of artificial fertilizer with manure, moreover, reduced the total amount of applied fertilizer because of a lack of regionally available manure. This reduction in amount of applied fertilizer reduced global warming potential (i.e. N_2O emission), and N and P surplus, but increased N and P deficit, and land occupation (effect of lower yield per ha).

The higher feed conversion of organic laying hens (2.59 kg feed kg^{-1} egg) compared with free range hens (2.33 kg feed kg^{-1} egg) was explained partly by an unbalanced amino acid profile of the diet of organic laying hens compared with free range hens (Van Krimpen et al., 2011). Optimization of the amino acid profile of the diet reduces feed conversion and, therefore, the ecological impact per kg egg. Optimization of the amino acid profile of the diet of organic laying hens is more difficult than for non-organic laying hens, because use of chemically produced amino-acids or amino-acids produced with genetically modified organisms is not allowed in organic agriculture. Other contributors to the higher feed conversion of organic laying hens may have been the limited use of medication and a lower number of hens per m^2 in the hen house, which generally results in a lower indoor temperature.

In chapter 5 we assessed the effect of replacing imported diet ingredients of the organic laying hen diet with Dutch diet ingredients. We expected that local production of diet ingredients would reduce the ecological impact, because two parameters that affect the ecological impact are improved, i.e. transport distance of feed and applied amount of manure. We did not know, however, to what extent this reduction would offset by changes in crop yield, feed conversion and cultivation that result from a geographical change of cultivation of diet ingredients. We found that replacement of Ukrainian wheat with Dutch triticale, and replacement of Brazilian soy beans, Italian sunflower seed expeller, and German peas with Dutch rapeseed expeller reduced ecological impact compared with current organic egg production. Simultaneous replacement of these diet ingredients was more effective than single replacement (Table 5.4) and resulted in a decrease of global warming potential (91%), energy use (79%), land occupation (68%), acidification potential (99%), N deficit (85%), P deficit (41%) and P surplus (81%), but also in a slight increase of N surplus (101%; current organic multi-tiered was set as 100%) (Table 6.2). We found the reduction in ecological impact was determined by: 1) reduction of the transport distance of 44.4% of the diet ingredients, 2) replacement of current used crops with crops that have higher yield in combination with a balanced amount of N and P in manure, and 3) use of expeller instead of whole ingredients, despite a small increase of the feed conversion (from 2.32 to 2.37 kg dry matter feed kg^{-1} egg).

Table 6.3 shows that the ecological impact in chapter 2 and 5 for current organic egg production differs. The reason for this difference is that in chapter 5 all arable diet ingredients were included, whereas in chapter 2 diet composition was simplified by replacing diet ingredients with a share smaller than 10% with main ingredients. This choice was made, because the objectives of chapter 2 and 5 differed. The objective of chapter 2 was to quantify ecological performance of the most commonly used egg production systems in the Netherlands and to identify which parameters explain differences in performance among systems. For this objective incorporation of only the main diet ingredients (i.e. maize, wheat, soy bean expeller, and sunflower expeller) was sufficient (type of ingredients were equal between the production systems), because the main parameters that explained differences among systems (i.e. feed conversion and type and amount of fertilizer applied) were evident. Chapter 5, however, focused specifically on the effect of replacement of diet ingredients and, therefore, required that all arable diet ingredients were included. The higher N and P surplus in chapter 5 compared with chapter 2 was explained by the large N and P surplus of the diet ingredient German peas, that was only included in Chapter 5. We conclude, therefore, that the ecological impact is rather sensitive to diet composition, because production of the diet has a major contribution to the ecological impact. Care, therefore, should be taken with simplification of diet composition when livestock products with different diet ingredients are compared. On the other hand, results from Chapter 5 show that the choice of diet ingredients offers the opportunity to reduce environmental impact.

Based on the results in Table 6.3 we conclude that replacement of imported diet ingredients with regional diet ingredients in organic egg production further reduces global warming potential and energy use, compared with non-organic egg production. Land occupation was reduced effectively by a higher amount of manure applied to organic crops, but remained higher than for non-organic egg production. Exchange of imported diet ingredients with regional diet ingredients hardly affected acidification potential. Differences in N and P surplus and N and P deficit between current organic diets and the scenario with Dutch diet ingredients were small compared with differences between organic and non-organic diets.

We conclude that prohibited use of external resources, currently increases part of the ecological impacts, because use of organic feed results in a higher feed conversion than non-organic feed and because of a lack of regionally available manure. Global warming potential, energy use and fossil P use, however, are reduced, because production and use of artificial fertilizer is avoided. Replacement of several imported diet ingredients with regional ones, will reduce the ecological impact of organic egg production, but land occupation, acidification potential, N deficit and P deficit will remain higher for organic than for non-organic egg production. We conclude that fertilization of organic diet ingredients needs to be optimized to increase crop yield, and to balance N and P levels in the soil. Moreover, diet composition must be optimized to obtain a low feed conversion, but only by using diet ingredients with a low ecological impact.

6.2. Conclusions and recommendations

Implementation of each of the three organic ethical requirements resulted in an increase of one or more ecological impacts. The requirement of loose hen housing resulted in an increase of all ecological impacts. The requirement access to an outdoor run resulted in a negligible increase of the ecological impact, whereas the requirement prohibited use of external resources increased only land occupation, acidification potential, N surplus and P surplus. These increases in ecological impact mainly resulted from inefficient manure management and inefficient conversion of feed to eggs. The search for mitigation options, therefore, should focus on improving manure management and feed conversion.

6.2.1. Manure management

Management of manure in the organic egg production chain determines the ecological impacts acidification potential (NH_3 emission), N and P deficit, and N and P surplus, and contributes to global warming potential (N_2O emission) and land occupation (yield per hectare). Loss of N and P not only affects the environment, it also means loss of N and P fertilizer from organic agriculture.

Issues in the current egg production chain regarding manure management are: 1) a lack of regionally available manure, 2) unbalanced application and N-P ratios of manure fertilizer, 3) high N-emissions from faeces in loose housing systems, and 4) loss of N and P from manure in the outdoor run. Production of diet ingredients and eggs in the same region to assure availability of manure, and multi-tiered housing to dry and remove manure contributes to reduction of the ecological impact.

Reduction of the ecological impact towards the level of non-organic egg production, however, requires more effective measures. The amount of applied manure to a crop needs to be high enough to obtain a high yield and avoid a N and P deficit and low enough to minimize N emissions from the field and avoid a N and P surplus. More specifically, the N-P ratio of applied manure needs to be known and adapted to the requirement of the crop. Unavoidable surpluses and deficits of individual crops may be levelled out by a crop rotation (i.e. variation of cultivation of crops on a field) (Nemecek and Baumgartner, 2006).

Further reduction of N emissions from loose hen housing should be focussed on reduction of interval of manure removal from the manure belts and reduction of N-emissions from the litter. Emissions of N from the litter can be reduced by increasing its dry matter content and regular removal of litter. Another solution would be use of air-scrubbers. Energy use of air scrubbers as well as recycling of N from the fluid, that captures N-gases from the exhaust air of the hen house, for fertilization, however, needs to be addressed from an integral perspective (Melse et al., 2009).

We proposed two options to reduce N and P loss to the outdoor run in chapter 5. The first option is to approach the outdoor run as a recreational area that adds space and daylight to the husbandry system (Groot Koerkamp and Bos, 2008). The N and P excreted in the outdoor run in this option is regularly removed either from a solid floor, by exchange of the soil, or by drainage and collection of leached N and P. To reduce costs, the surface of the outdoor run of this mitigation option needs to be reduced. The second option is to approach the outdoor run as a forage area that adds space, daylight and a foraging opportunity to the husbandry system. In this option grazing by hens is managed to assure even grazing and fertilization of the outdoor run, for example, by keeping hens in small movable accommodations or by strip grazing (Horsted et al., 2006; Keeling, 1988).

6.2.2. Feed conversion

Implementation of all three requirements results in an increase of the feed conversion from 1.99 to 2.59 kg feed kg^{-1} egg. Feed conversion increased most for the requirement loose hen housing (0.34 kg feed kg^{-1} egg), intermediate for prohibited use of external resources (0.26 kg feed kg^{-1} egg), and least for access to the outdoor run (0.05 kg feed kg^{-1} egg). The higher feed conversion resulting from loose hen housing is caused by a higher body mass of loose housed hens (Table 2.5) and increased freedom of movement (Van Knegsel and van Krimpen, 2008). The higher feed conversion resulting from prohibited use of external resources is caused by a worse amino acid profile of the diet. Limited use of medication and a lower number of hens per m^2 in the hen house, which generally results in a lower indoor temperature, however, may also have contributed to a higher feed conversion. The higher feed conversion resulting from access to the outdoor run may be caused by a lower environmental temperature, increased activity, and exposure to pathogens in the outdoor environment (Van Knegsel and van Krimpen, 2008). Research is required to determine whether an increase of the feed conversion in organic egg production must be accepted as an implication of the organic ethical framework or can be improved within the boundaries of the organic ethical framework.

6.2.3 Interdependency between arable and livestock farming

Reduction of the ecological impact is possible within the boundaries of the organic ethical framework and mitigation options are straightforward, but quite drastic. To achieve improvement of the ecological impact within the boundaries of the organic ethical framework, an interdependency between livestock and arable production needs to be created. The concept of interdependency fits very well to the principles of fairness and care of organic agriculture. Livestock and arable farmers need to work together to create an efficient N and P cycle, that results in a productive conversion of land occupation into eggs. To realize the N and P cycle, use of non-organic manure in organic agriculture must be fully prohibited and trade of feed and manure must be transparent. A good example of cooperation between arable and livestock production is biodynamic agriculture (http://www.biodynamic.org.uk/). Biodynamic livestock farmers produce 50% of their feed themselves or have an exchange arrangement for feed and manure with an arable farmer. This cooperation realizes interdependency and interaction regarding exchange of products. Interdependency and interaction could also be arranged on an international level. Companies that import feed in that case should take responsibility for balancing N and P at a regional level, by exporting (treated) manure. A disadvantage of international exchange of nutrients in feed and manure, however, is that transport distance of feed and manure is not reduced and the large distance between arable and animal farmers may hamper mutual understanding.

6.2.4. Use of the results

Putting production systems in boxes that are stamped as either "good" or "bad" is not a conclusion that can be drawn from an integral sustainability assessment, because several issues along the production chain are addressed simultaneously. Integral sustainability assessment is meant as a tool to identify the strengths and weaknesses of a production system. These strengths and weaknesses should rather be used as a starting point for innovative systems design than to simply judge a product. The results from this thesis should, therefore, not be used to set aside the ethical framework, but as a starting point to reduce ecological impact of eggs within the boundaries of their ethical framework.

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Summary

Summary

Ecological sustainability is a broad concept that unites ecological issues caused by human activities. Ecological issues generally associated with agriculture are: global warming, fossil energy depletion, land occupation, fossil phosphorus (P) depletion, acidification, eutrophication, soil depletion, biodiversity and eco-toxicity. Agriculture inevitably affects the environment, because agriculture is a human activity taking place in the natural environment. Agriculture without an ecological impact, therefore, is a utopia. The integral ecological impact (i.e. impact along the production chain) of a production system, depends on its production characteristics.

Organic agriculture has a specific perspective on sustainable agriculture, captured in their goal, definition and four principles of organic agriculture (see section 1.2). This perspective is converted to practical rules for organic production. In this thesis this specific perspective, i.e. IFOAM's goal, definition, principles and resulting rules, is referred to as the organic ethical framework. The organic ethical framework sets borders to the production characteristics of organic production systems. The organic ethical framework for organic eggs resulted in three specific requirements, i.e. loose hen housing, access to an outdoor run, and prohibited use of external resources. The effect of the organic ethical framework on the ecological impact of organic egg production systems, however, is unknown.

The main objective of this thesis was to assess the effect of the organic ethical framework on the integral ecological impact of Dutch organic egg production. This objective was approached from three angles: 1) determination of the difference in integral ecological impact of egg production with and without an organic ethical framework, 2) identification of the main ecological issues in the current Dutch organic egg production system, and 3) exploration of options to improve integral ecological impact of Dutch organic egg production within the borders of the organic ethical framework. The three sub-questions of this thesis were: what is the effect of loose hen housing on the integral ecological impact of organic egg production; what is the effect of presence of an outdoor run on the integral ecological impact of egg production; and what is the effect of exclusion of external resources on the integral ecological impact of organic egg production?

In chapter 2, we quantified the ecological performance of the most commonly used egg production systems in the Netherlands, and identified which factors explain differences in performance. We included the conventional battery cage system and the following loose housing systems:

single and multi-tiered barn systems, single and multi-tiered free range systems, and single and multi-tiered organic systems. Ecological indicators used were deduced from a life cycle assessment (LCA), and were: global warming potential, energy use, land occupation, fossil P use, acidification potential, nitrogen (N) and P deficit, and N and P surplus, each expressed per kg of egg. Based on our ecological evaluation of Dutch egg production systems, we predict that a ban on battery cages in the European Union will increase global warming potential, land occupation and acidification potential per kg of egg produced, whereas the effect on energy use, fossil P use, N and P deficit, and N and P surplus, will depend on the shares of hens housed in single-tiered and multi-tiered houses. Of all loose housing systems, organic systems had the lowest global warming potential, energy use, fossil P use, and N and P surplus, whereas land occupation and N and P deficit was lowest for barn systems. Within loose housing systems, acidification potential was lowest for a multi-tiered barn system. Differences in LCA results among production systems can be explained mainly by differences in feed conversion, in parameters that determine ecological impact per kg feed ingredient (e.g. crop yield per ha; number of field operations, type and amount of fertilization), drying of grain, transport of concentrates and manure, type of hen house and nitrogen excretion per hen per year.

In Chapter 3, we first assessed the year-round emissions of ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) from three commercial aviary systems with organic laying hen husbandry. Second, we determined the effect of varying removal intervals of manure on NH_3, N_2O and CH_4 emissions when using manure belts. Emissions were computed from the ventilation rate, calculated with the carbon dioxide (CO_2) mass balance method, and gas concentrations of NH_3, N_2O, and CH_4 inside and outside the hen house. Mean emission per hen for NH_3 was 410 mg d^{-1}, for N_2O was 3.12 mg d^{-1}, and for CH_4 was 81.7 mg d^{-1}. Mean predicted emission per hen for NH_3 on the first day after manure removal was 298 mg d^{-1}, and increased by 5.47% d^{-1}. The presence of manure on the belt did not affect emissions of N_2O and CH_4. Emission of NH_3 from aviary systems with organic laying hen husbandry was in the same range as emission of NH_3 from aviary systems with non-organic laying hen husbandry. Organic laying hen husbandry in aviary systems instead of single-tiered systems has the potential to substantially reduce emissions of NH_3. Further reductions might be realised by changes in litter management.

In chapter 4, we determined the level and variation of the total mass, and load of nitrogen (N) and phosphorus (P) excreted into the outdoor run of organic laying hen farms. Three farms with an aviary system and an outdoor run were selected for this study. Four measurements, one per season, were

executed on each farm. Mean content of N and P of a manure dropping was 14.0 g N kg^{-1} (SD 1.75) and 3.12 g P kg^{-1} (SD 0.49), mean mass of a dropping was 6.36 g (SD 0.67) and mean dry matter content of a dropping was 238 g kg^{-1} (SD 32). Mean rate of excretion in the outdoor run was 2.99 droppings per hen per hour. Mean percentage of hens outside during the time the outdoor run could be accessed was lowest on farm 1 (1.7%), highest on farm 2 (13.0%), and mediate on farm 3 (7.1%). On all farms an exponential decrease of the number of hens and of the load of N and P with increasing distance from the hen house was found. In this study load of N exceeded the fertilization standard (of 170 kg ha^{-1} y^{-1}) in the region 0 to 19 m distance from the hen house on farm 1, 0 to 146 m on farm 2 and 0 to 52 m on farm 3. Total mass of N and P excreted into the outdoor run varied from 1.7% to 16.1% of total N and 1.4% to 17.5% of total P excretion. It is concluded that the husbandry system should be redesigned to solve the problems of overloading, unwanted losses of N and P to the environment, and loss of N and P from the organic production cycle.

In Chapter 5, we assessed the potential to reduce the integral ecological impact (i.e. impact along the egg production chain per kg egg) of Dutch organic egg production by replacing currently used imported diet ingredients with Dutch diet ingredients. We realized this objective by comparing the life cycle assessments of current Dutch organic egg production with different scenarios. In each scenario, one imported diet ingredient was replaced with a diet ingredient produced in the Netherlands. Finally, we formulated a scenario in which several ingredients, that individually resulted in the lowest mean change in ecological impact along the organic egg production chain, were replaced simultaneously. Differences between scenarios included in the research were: cultivation characteristics (i.e. field operation, manure application and yield), transport type and distance, feed intake, mass of egg production and N excretion. Replacement of Ukrainian wheat with Dutch triticale, and of Brazilian soy beans, Italian sunflower seed expeller and German peas with Dutch rapeseed expeller reduced the integral ecological impact compared with current organic egg production. Simultaneous replacement of these ingredients (scenario MU) resulted in a lower mean ecological impact (80.6%) than single replacement of these ingredients (93.5% to 111.9%) compared with current organic egg production (set to 100%). Compared with current egg production ecological impact of scenario MU decreased for global warming potential (91%), energy use (79%), land occupation (68%), acidification potential (99%), N deficit (85%), P deficit (41%) and P surplus (81%), but slightly increased for N surplus (101%). The low ecological impact of MU was explained by: 1) a reduction of the transport distance of 44.4% of the diet ingredients, 2) replacement of current used crops with crops that have a higher yield in combination with a balanced applied amount of N and P in manure, and 3) use of expeller instead of whole ingredients. These effects on the ecological impact were larger than the effect of a small increase of the feed conversion in the MU scenario.

The organic ethical framework for organic eggs resulted in three specific requirements, i.e. loose hen housing, access to an outdoor run, and prohibited use of external resources. Comparison of egg production in non-organic battery cages and single-tiered houses showed that the requirement of loose hen housing results in a 12% to 176% higher impact for the ecological issues studied, except for P deficit which was equal. This higher impact is mainly explained by a higher feed conversion of loose housed hens (2.33 kg feed kg^{-1} egg) compared with hens in battery cages (1.99 kg feed kg^{-1} egg). Organic laying hens in the Netherlands are mainly kept in single-tiered houses. A second reason for the higher acidification potential of non-organic single-tiered egg production compared with battery cage egg production, therefore, was that in single-tiered houses faeces is collected as litter on floors and as manure in a pit, and removed after the production round (396 to 406 days), whereas in battery cages all manure is air-dried on manure belts and removed every five days. Removal and drying of manure reduces emissions of NH_3, N_2O and CH_4 from the hen house. Housing organic hens in multi-tiered hen houses instead of single-tiered hen houses will reduce acidification potential, but not to the level of battery cages, because not all manure is collected on belts, air-dried and removed from the hen house. Loose hen housing, however, will be common practice in the EU from 2012 onwards. This perspective demands development of a loose hen housing system with NH_3 emissions that are comparable with battery cages. An option to further reduce NH_3 emission was daily removal of manure from the belts and increase of the dry matter content of the litter, for example by addition of more bedding material. Another solution would be use of air-scrubbers. Energy use of air scrubbers as well as recycling of N from the fluid, that captures N-gases from the exhaust air of the hen house, for fertilization, however, needs to be addressed from an integral perspective. Moreover, parameters that affect the difference in feed conversion between battery cage and loose hen husbandry, such as a higher body mass and increased freedom of movement of loose housed hens, need to be further explored and, subsequently, used to reduce feed conversion of loose housed laying hens.

Comparison of non-organic single-tiered indoor and single-tiered outdoor egg production showed that the requirement of access to an outdoor run results in a relative small increase of the impact of the issues studied (2% to 9%). This increase was explained by a slightly higher feed conversion of hens with access to an outdoor run (2.33 kg feed kg^{-1} egg), than of hens without access to an outdoor run (2.28 kg feed kg^{-1} egg). Access to an outdoor run may increase feed conversion, because of a lower environmental temperature, increased activity, and exposure to pathogens in the outdoor environment. The outdoor run is intended to improve laying hen welfare, but in practice only few hens are outside. More intensive use of the outdoor run, therefore, should be stimulated. If use increases, however, ecological impact will also increase. This increase of the ecological impact should be avoided. One option to reduce N and P loss to the outdoor run is regular removal of manure either from a solid floor, by exchange of the soil, or by drainage and collection of leached N and P. To reduce costs, the surface of the outdoor run of this mitigation option needs to be reduced. Another option to reduce N and P loss to the outdoor run is management towards even grazing and fertilization of the outdoor run by hens, for example, by keeping hens in small movable accommodations or by strip grazing.

Currently prohibited external resources in organic agriculture are: artificial fertilizers, pesticides, herbicides, genetically modified organisms and moreover, only limited use of medication is allowed. Comparison of multi-tiered organic and non-organic free range egg production showed that the requirement of prohibited use of external resources results in a lower global warming potential (93%), energy use (88%), fossil P use (22%), and N (11%) and P surplus (8%), but higher land occupation (166%), acidification potential (115%), and N (1425%) and P deficit (1000%; non-organic multi-tiered-free range was set as 100%). We found that differences in ecological impact between organic and free range egg production were determined mainly by type and amount of fertilization and feed conversion.

Replacement of artificial fertilizer with manure reduced global warming potential (i.e. CO_2 emission), energy use, and fossil P depletion, because fossil energy and fossil P required for production of artificial fertilizer was avoided. Replacement of artificial fertilizer with manure, moreover, reduced the total amount of applied fertilizer, because of a lack of regionally available manure. A lower amount of applied manure resulted in a reduction of global warming potential (i.e. N_2O emission), and N and P surplus, but an increase of N and P deficit, and land occupation (effect of lower yield per ha). The higher feed conversion of organic laying hens was explained partly by an unbalanced amino acid profile of the diet of organic laying hens compared with free range hens. The amino acid profile of the organic diet was unbalanced, because use of chemically produced amino-acids or amino-acids produced with genetically modified organisms is not allowed in organic agriculture.

Replacement of several imported diet ingredients with regional ones, will reduce the ecological impact of organic egg production, but land

occupation, acidification potential, N deficit and P deficit will remain higher for organic than for non-organic egg production. Fertilization of organic diet ingredients needs to be optimized to increase crop yield, and to balance N and P levels in the soil. More specifically, the N-P ratio of applied manure needs to be known and adapted to the requirement of the crop. Unavoidable surpluses and deficits of individual crops may be levelled out by a crop rotation (i.e. variation of cultivation of crops on a field). Moreover, diet composition must be optimized to obtain a low feed conversion, but only by using diet ingredients with a low ecological impact.

It was concluded that the organic ethical framework increased the ecological impact, mainly because of inefficient manure management and inefficient conversion of feed to eggs. The search for mitigation options, therefore, should focus on improving manure management and feed conversion. Reduction of the ecological impact is possible within the boundaries of the organic ethical framework and mitigation options are straightforward, but quite drastic. To achieve improvement of the ecological impact within the boundaries of the organic ethical framework, an interdependency between livestock and arable production needs to be created.

Integral sustainability assessment is meant as a tool to identify the strengths and weaknesses of a production system. These strengths and weaknesses should rather be used as a starting point for innovative systems design than to simply judge a product. The results from this thesis should, therefore, not be used to set aside the ethical framework, but as a starting point to reduce ecological impact of eggs within the boundaries of their ethical framework.

Samenvatting

Ecologische duurzaamheid omvat het duurzaam gebruik van hulpstoffen en het minimaliseren van negatieve effecten van emissies naar bodem, water en lucht. Het produceren van voedsel is onlosmakelijk verbonden met het gebruik van hulpstoffen en emissies naar het milieu. Landbouw zonder gebruik van hulpstoffen en emissies naar het milieu is dan ook een utopie. Ecologische duurzaamheidsthema's die veelal met de landbouw geassocieerd worden zijn: het broeikaseffect, uitputting van fossiele brandstoffen, uitputting van fossiel fosfaat (P), verzuring, eutrofiëring, bodemuitputting, verlies van biodiversiteit en emissie van toxische stoffen. De integrale milieubelasting (i.e. de belasting van de hele productieketen) van een landbouwsysteem, hangt af van diens productiekarakteristieken.

De visie van de biologische landbouw op duurzaamheid is verwoord door IFOAM in hun doelstelling en de vier beginselen van de biologische landbouw (zie Sectie 1.2; IFOAM, 2011) en is vertaald in diverse praktische regels voor biologische productie. In dit proefschrift noemen we deze visie het biologisch-ethisch kader. Dit ethisch kader stelt grenzen aan de productiekarakteristieken van biologische productiesystemen. Voor de productie van biologische eieren resulteert dit in drie specifieke eisen: (1) scharrelhuisvesting van hennen, i.e. grond- en volièrehuisvesting (2) toegang tot een uitloop voor de hennen en (3) een verbod op het gebruik van externe hulpbronnen, i.e. kunstmest, pesticiden, herbiciden, genetisch gemodificeerde organismen en beperkt gebruik van medicijnen. Het effect van het biologisch-ethisch kader op de ecologische duurzaamheid van biologische eiproductiesystemen is echter onbekend.

De hoofddoelstelling van dit proefschrift was het vaststellen van het effect van dit biologisch-ethisch kader op de integrale milieubelasting van biologische eiproductie in Nederland. Deze doelstelling werd benaderd vanuit drie invalshoeken: 1) het vaststellen van het verschil in integrale milieubelasting van eiproductie met en zonder het biologisch-ethisch kader, 2) het identificeren van de belangrijkste milieuproblemen in het bestaande biologische eiproductiesysteem in Nederland en 3) het verkennen van mogelijkheden om de integrale milieubelasting van Nederlandse biologische eiproductie te verbeteren binnen de grenzen van het biologisch-ethisch kader. De drie deelvragen van dit proefschrift waren:

1. Wat is het effect van scharrelhuisvesting van hennen op de integrale milieubelasting van biologische eiproductie?;
2. Wat is het effect van aanwezigheid van een uitloop op de integrale milieubelasting van eiproductie?;

3. En wat is het effect van een verbod op gebruik van externe hulpbronnen op de integrale milieubelasting van biologische eiproductie?

Hoofdstuk 2 beschrijft de milieuprestaties van de meest voorkomende eiproductiesystemen in Nederland en de belangrijkste factoren die de verschillen in prestaties tussen de systemen verklaren. We hebben gangbare batterijhuisvesting en de meest voorkomende scharrelhuisvestingsystemen geanalyseerd (i.e. grond- en volièrehuisvesting, huisvesting met en zonder uitloop en biologisch). De gehanteerde milieu-indicatoren zijn afgeleid van de levenscyclus analyse (LCA) en uitgedrukt per kg ei. Deze milieu-indicatoren zijn: broeikaspotentieel, fossiel energiegebruik, landgebruik, fossiel P gebruik, verzuringspotentieel, stikstof (N) en P tekort, en N en P overschot. Op basis van deze milieu-evaluatie van Nederlandse eiproductiesystemen, voorspellen we dat een verbod op batterijhuisvesting in de Europese Unie zal resulteren in een toename van het broeikaspotentieel, het landgebruik en het verzuringspotentieel per kg ei. Het effect van een verbod van batterijhuisvesting op energie gebruik, fossiel P gebruik, N en P tekort, en N en P overschot per kg ei hangt af van het aandeel hennen dat gehuisvest zal worden in de verschillende scharrelsystemen. Het biologische systeem had het laagste broeikaspotentieel, energiegebruik, fossiel P gebruik, en N en P overschot van alle scharrelsystemen. Landgebruik en N en P tekort bleek het laagst voor grondhuisvesting zonder uitloop en verzuringspotentieel voor volièrehuisvesting zonder uitloop. Verschillen in LCA resultaten tussen productiesystemen worden vooral verklaard door verschillen in voederconversie, parameters die de milieubelasting per kg voer bepalen (bijv. opbrengst per ha, aantal grondbewerkingen, type en hoeveelheid bemesting), wel of niet drogen van graan, transporteren van voer en mest, type huisvesting en N uitscheiding per hen per jaar.

Hoofdstuk 3 beschrijft de resultaten van de gemeten jaargemiddelde emissies van ammoniak (NH_3), lachgas (N_2O) en methaan (CH_4) van drie biologische leghennenbedrijven met volièrehuisvesting. Dit hoofdstuk beschrijft eveneens het effect van tijdstip van mestverwijdering van de mestbanden op de emissies van NH_3, N_2O en CH_4. De emissies van deze gassen zijn vastgesteld op basis van het indirect gemeten ventilatiedebiet (CO_2 massabalans methode) en de gemeten gasconcentraties van NH_3, N_2O en CH_4 binnen en buiten de stal. De gemiddelde emissie per hen was 410 mg NH_3 d^{-1}, 3.12 mg N_2O d^{-1} en 81.7 mg CH_4 d^{-1}. De voorspelde NH_3 emissie per hen op de eerste dag na mestverwijdering was 298 mg d^{-1} en nam toe met 5.47% d^{-1}. De hoeveelheid mest op de mestband had geen effect op de emissie van N_2O en CH_4. De emissie van NH_3 uit biologische volièrehuisvesting was vergelijkbaar met die uit gangbare volièrehuisvesting zonder uitloop. De biologische leghennenhouderij kan haar NH_3 emissie substantieel verlagen door over te stappen van grondhuisvesting naar volièrehuisvesting, en regelmatig de mestband af te draaien (b.v. één maal per dag). Een verdere verlaging van N emissies zou gerealiseerd kunnen worden door aanpassingen in het strooiselmanagement.

Hoofdstuk 4 beschrijft het niveau en de variatie van de N en P uitscheiding in de uitloop op drie biologische leghennenbedrijven. Vier metingen, één per seizoen, werden uitgevoerd op ieder bedrijf. Het N en P gehalte van een mesthoopje was gemiddeld 14.0 g N kg^{-1} (SD 1.75) en 3.12 g P kg^{-1} (SD 0.49). De gemiddelde massa van een mesthoopje was 6.36 g (SD 0.67), het gemiddelde droge stof gehalte was 238 g kg^{-1} (SD 32). Het gemiddelde percentage hennen dat buiten liep in de periode dat de uitloop toegankelijk was, bleek het laagst op bedrijf 1 (1.7%), het hoogst op bedrijf 2 (13%) en gemiddeld op bedrijf 3 (7.1%). Op alle bedrijven nam het aantal aanwezige hennen en de N en P belasting per ha exponentieel af met de afstand tot de stal. De N belasting was hoger dan de bemestingsnorm voor intensief grasland van 170 kg ha^{-1} $jaar^{-1}$ binnen een afstand van 0 tot 19 m van de stal op bedrijf 1, van 0 tot 146 m op bedrijf 2 en van 0 tot 52 m op bedrijf 3. De N en P uitscheiding in de uitloop varieerde van 1.7% tot 16.1% van de totale N uitscheiding, en van 1.4% tot 17.5% van de totale P uitscheiding. De conclusie is dat het biologische houderijsysteem moet worden aangepast om de overbelasting van N en P in de uitloop en gerelateerde N en P verliezen naar het milieu te verminderen.

Hoofdstuk 5 beschrijft de resultaten van een scenario-studie naar de mogelijkheid om door het veranderen van de voersamenstelling de integrale milieubelasting van Nederlandse biologische eiproductie te verminderen. We hebben dit gedaan door LCA resultaten van de huidige Nederlandse biologische eiproductie te vergelijken met die van diverse scenario's waarin steeds één geïmporteerd voeringrediënt werd vervangen door een in Nederland geteelde ingrediënt. Bovendien hebben we een geïntegreerd scenario bestudeerd. In dit scenario zijn de verschillende voeringrediënten, die individueel resulteerden in een lage gemiddelde milieubelasting, tegelijkertijd vervangen. De diverse scenario's zijn vergeleken ten aanzien van: teeltkarakteristieken (i.e. grondbewerking, mestaanwending en oogst), transport type en afstand, voeropname, geproduceerde ei-massa (i.e. de voederconversie) en N excretie. Het vervangen van Oekraïense tarwe door Nederlandse triticale, en het vervangen van Braziliaanse sojaschilfers, Italiaanse zonnepitschilfers en Duitse erwten door Nederlandse koolzaadschilfers, verminderde de integrale milieubelasting in vergelijking met huidige biologische eiproductie. Het gelijktijdig vervangen van deze ingrediënten (MU scenario) resulteerde in een lagere gemiddelde milieubelasting (80.6%) dan enkelvoudige vervanging (93.5% tot 111.9%), in vergelijking met de huidige biologische eiproductie (vastgesteld op

100%). Ondanks de iets hogere voederconversie van het MU scenario, was de milieubelasting van dit scenario beduidend lager voor broeikaspotentieel (91%), energiegebruik (79%), landgebruik (68%), verzuringspotentieel (99%), N tekort (85%), P tekort (41%) en P overschot (81%). Het N overschot in het MU scenario was echter iets hoger dan in de huidige situatie (101%). De lagere milieubelasting van het MU scenario kon worden verklaard door: 1) een afname van de transportafstand van 44.4% van de voeringrediënten, 2) vervanging van momenteel gebruikte gewassen door gewassen met een hogere opbrengst per ha in combinatie met een meer uitgebalanceerde N en P bemesting en 3) gebruik van bijproducten, zoals (koolzaad) schilfers, in plaats van hoofdproducten, zoals erwten.

Het biologisch-ethisch kader resulteerde voor biologische eiproductie in drie specifieke eisen: 1) scharrelhuisvesting van hennen; 2) toegang tot een uitloop en 3) een verbod op het gebruik van externe hulpbronnen. Een vergelijking van de eiproductie in gangbare batterij- en scharrelhuisvesting liet zien dat de eis ten aanzien van scharrelhuisvesting van hennen resulteerde in een 12% tot 176% hogere milieubelasting voor bijna alle bestudeerde duurzaamheidsthema's. Alleen het P tekort bleef gelijk. Deze hogere belasting wordt vooral verklaard door een hogere voederconversie van hennen in scharrelhuisvesting (2.33 kg voer kg^{-1} ei) in vergelijking met hennen in batterijhuisvesting (1.99 kg voer kg^{-1} ei). Biologische leghennen in Nederland worden vooral gehouden in grondhuisvesting. Het hogere verzuringspotentieel van gangbare eiproductie in grondhuisvesting als gevolg van de emissie van ammoniak wordt bovendien verklaard door de ophoping van mest in het strooisel op de vloer en verzameling van mest in de beun, die beiden pas aan het einde van de legronde worden verwijderd (na 398 dagen). In batterijhuisvesting wordt alle mest op de band met lucht gedroogd en bovendien iedere vijf dagen verwijderd.

Het verwijderen en drogen van mest vermindert de stalemissies van NH_3, N_2O en CH_4. Het huisvesten van hennen in een volière- in plaats van een grondhuisvesting zal het verzuringspotentieel verminderen, maar niet tot het niveau van batterijhuisvesting, omdat in tegenstelling tot in het batterijsysteem in een volièresysteem niet alle mest wordt verzameld op mestbanden en met lucht wordt gedroogd, en vervolgens wordt verwijderd uit de stal. Per 1 januari 2012 is traditionele batterijhuisvesting van hennen verboden in de Europese Unie. Dit gegeven vraagt om de ontwikkeling van scharrelhuisvesting voor hennen met NH_3 emissies die vergelijkbaar zijn met de traditionele batterij. Een mogelijkheid om de NH_3 emissie verder te verlagen is dagelijks verwijderen van mest van de mestbanden en verhogen van het droge stofgehalte van de strooiselmest, bijvoorbeeld door het toevoegen van meer strooisel. Een andere oplossing is het gebruik van luchtwassers in de uitgaande ventilatielucht. Zowel het energiegebruik van luchtwassers, als het recyclen van N uit de vloeistof die wordt gebruikt om NH_3 in de uitgaande stallucht te binden, moet worden opgenomen in een integrale evaluatie van deze oplossingsrichting. Bovendien is het nodig om de voederconversie van hennen in scharrelhuisvesting te verlagen. Dit vereist onderzoek naar factoren die het verschil in voederconversie tussen hennen in batterij- en scharrelhuisvesting verklaren, zoals het lichaamsgewicht (lager in batterij) en de bewegingsvrijheid (minder in batterij).

Een vergelijking van gangbare scharrelhuisvesting met en zonder uitloop liet zien dat de eis ten aanzien van toegang tot een uitloop resulteerde in een relatief kleine toename van de bestudeerde milieu-indicatoren (2% tot 9%). Deze toename werd verklaard door een iets hogere voederconversie van hennen met toegang tot een uitloop (2.33 kg voer kg^{-1} ei) in vergelijking met hennen zonder toegang tot een uitloop (2.28 kg voer kg^{-1} ei). Mogelijke redenen voor deze hogere voederconversie van hennen met toegang tot een uitloop zijn een lagere omgevingstemperatuur (zowel in de stal als buiten), een toename van de activiteit en blootstelling aan pathogenen in de uitloop. De uitloop is bedoeld om het welzijn van de leghen te verbeteren, maar in de praktijk lopen maar weinig hennen buiten. Dit onderzoek laat zien dat het stimuleren van een intensiever gebruik van de uitloop eveneens leidt tot een hogere milieubelasting van de uitloop. Mogelijkheden tot vermindering van het N en P verlies in de uitloop zijn: het regelmatig verwijderen van mest van een verharde ondergrond, het regelmatig afgraven van de bodem in de uitloop dicht bij de stal, of het draineren en verzamelen van uitgespoelde N en P. Om de kosten te beperken zal het oppervlak van de uitloop voor deze oplossingsrichting moeten worden gereduceerd. Een andere mogelijkheid om het N en P verlies naar de uitloop te verlagen is management gericht op gelijkmatige begrazing en bemesting van de uitloop door hennen, bijvoorbeeld door de hennen in kleine verplaatsbare behuizing te houden of door strip-begrazing toe te passen.

De volgende externe hulpbronnen zijn momenteel verboden in de biologische landbouw: kunstmest, pesticiden, herbiciden en genetisch gemodificeerde organismen. Het gebruik van medicijnen is slechts beperkt toegestaan. Een vergelijking van biologische en gangbare volièrehuisvesting met uitloop liet zien dat de eis van een verbod op het gebruik van externe hulpbronnen resulteerde in een lager klimaatveranderingspotentieel (93%), energiegebruik (88%), fossiel P gebruik (22%), en N (11%) en P overschot (8%), maar in een hoger landgebruik (166%), verzuringspotentieel (115%), en N (1425%) en P tekort (1000%; gangbaar is 100%). Deze verschillen in milieubelasting worden voornamelijk bepaald door type en hoeveelheid bemesting tijdens de teelt van voedergewassen en verschillen in voederconversie.

Het vervangen van kunstmest door mest leidt tot een vermindering van het broeikaspotentieel (i.e. CO_2 emissie), het energiegebruik en fossiel P gebruik. Dit komt doordat voor het maken van kunstmest fossiele energie en fossiel P nodig is. Het vervangen van kunstmest leidde in dit onderzoek eveneens tot een afname van de totale hoeveelheid aangewende meststof per ha vanwege een regionaal tekort van beschikbare mest. Dit resulteerde in een relatief laag broeikaspotentieel (i.e. N_2O emissie) en een laag N en P overschot in biologische eiproductie, maar een relatief hoog N en P tekort, en landgebruik (effect van een lagere opbrengst per hectare). Een te lage bemesting van gewassen leidt tot verarming van de bodem en is derhalve niet duurzaam.

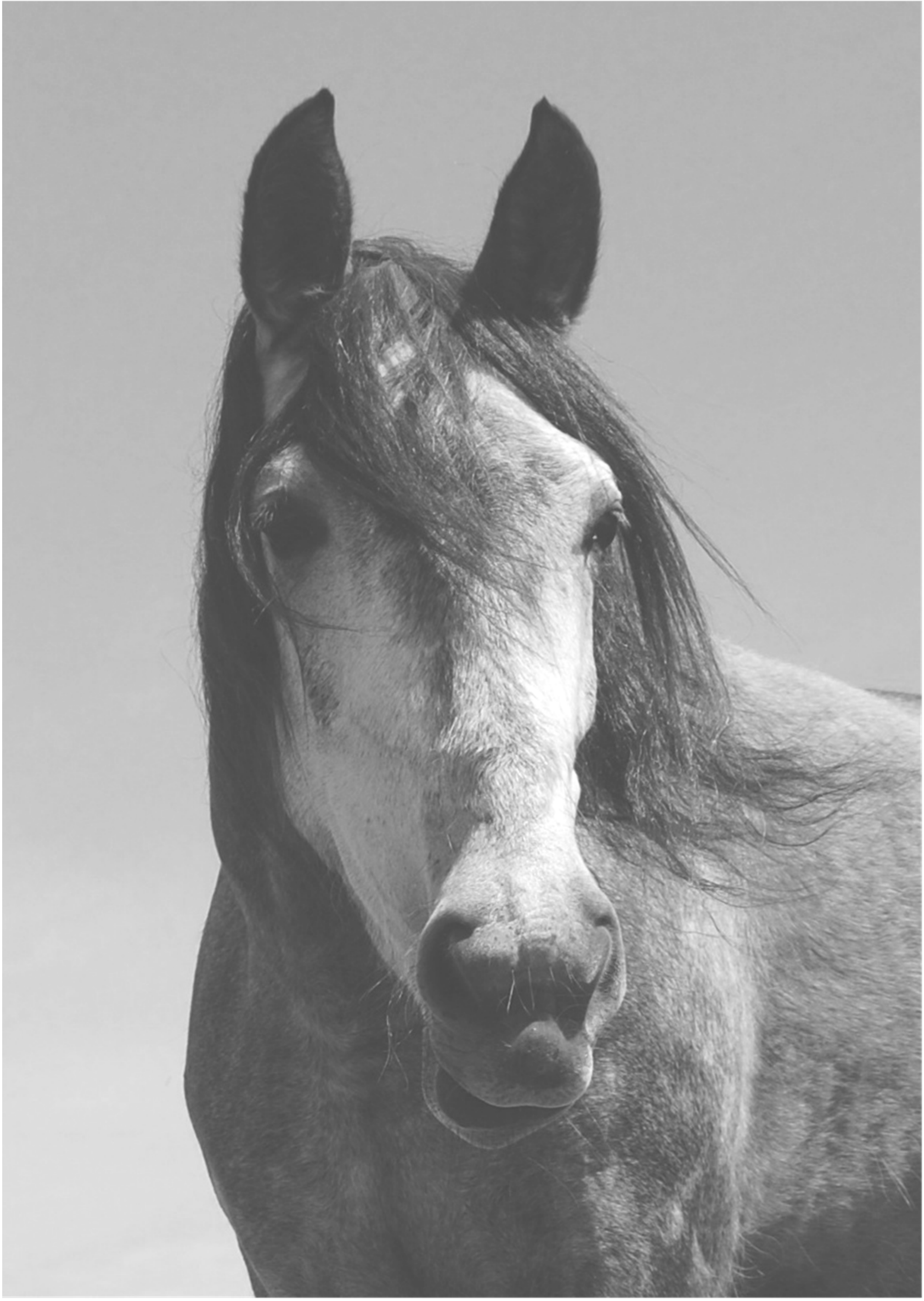
De hogere voederconversie van biologische leghennen werd deels verklaard door een niet gebalanceerd aminozuurprofiel van het dieet van biologische leghennen. Het aminozuurprofiel van het biologische dieet is niet gebalanceerd omdat het gebruik van aminozuren geproduceerd door genetische gemodificeerde organismen niet is toegestaan in de biologische landbouw.

Het vervangen van bepaalde geïmporteerde voeringrediënten door regionale ingrediënten kan de milieubelasting van biologische eiproductie verlagen, maar het landgebruik en het verzuringspotentieel zullen hoger blijven voor biologische dan voor gangbare eiproductie. Om gewasopbrengsten te verhogen, het landgebruik te verlagen en de N en P tekorten in de bodem te vermijden is optimale gewasbemesting van groot belang. Dit betekent onder andere dat de N-P-verhouding van de aangewende mest bekend zijn en moeten worden aangepast aan de eisen van het gewas. Niet te voorkomen overschotten en tekorten van individuele gewassen zouden kunnen worden uitgebalanceerd door vruchtwisseling (i.e. variatie van verbouwde gewassen op een perceel). Bij het samenstellen van het dieet moet echter niet alleen gekeken worden naar de milieubelasting van de voeringrediënten, maar ook naar de uiteindelijke voederconversie van het dieet.

De conclusie is dat het biologisch-ethisch kader de milieubelasting van eiproductie vooral doet toenemen, vanwege een inefficiënt mestmanagement en een inefficiënte conversie van voer naar eieren. De zoektocht naar oplossingen moet zich dan ook richten op het verbeteren van het mestmanagement in de gehele keten en de voederconversie. Verlagen van de milieubelasting is mogelijk binnen de grenzen van het biologisch-ethisch kader en oplossingsrichting zijn vrij voor de hand liggend, maar ook drastisch.

Om een verbetering van de milieubelasting binnen de grenzen van het biologisch-ethisch kader te realiseren moet een wederzijdse afhankelijkheid van dierlijke en plantaardige productie worden gerealiseerd. Integrale duurzaamheid is bedoeld als een middel om de sterke en zwakke kanten van een productiesysteem te identificeren. Deze sterke en zwakke kanten worden bij voorkeur gebruikt als een uitgangspunt voor innovatief systeemontwerp in plaats van het simpelweg beoordelen van een product. Het resultaat van dit proefschrift moet dan ook niet worden gebruikt om het ethisch kader te veranderen, maar het zou als uitgangspunt moeten dienen voor het verlagen van de milieubelasting van eieren binnen de grenzen van het ethisch kader.

Nawoord



Nawoord

Ooit, niet zo heel lang geleden, was er een meisje dat midden in het bos een paard vond. Het was een mooi wit paard, maar nog jong en wild. Het meisje ging zitten en wachtte tot het paard uit zichzelf naar haar toekwam. Toen bond ze een touw om het paard zijn hals en nam hem mee naar huis. Op de weg naar huis moest ze een zevensprong oversteken. Ze stond net midden op de kruising te twijfelen welke weg ze ook weer in moest, toen uit een van de paden met vliegende vaart een koets met vier krachtige gitzwarte paarden kwam aangestoven. De koetsier fluisterde 'halt' en vlak voor het meisje kwamen de paarden in zo'n vloeiende beweging tot stilstand, dat het net leek alsof het maar één paard was. De mond van het meisje viel open van verbazing en ze flapte eruit 'Dat wil ik ook kunnen'. De koetsier zei 'Dat kan, maar het is een lange weg, niet alleen voor het paard, maar ook voor jou. Je moet de weg helemaal zelf stapje voor stapje aflopen. Je kunt niet afsnijden en met niemand anders meeliften. Als je dat wel doet, loop je de kans dat de geur van die mooie bloesem die jij in je hand hebt, voor altijd vervliegt'. Het meisje keek verbaasd naar haar handen, maar zag alleen het touw waar het paard aan vast zat. De koetsier zei 'Je hebt een prachtig paard, wil je mij een plezier doen?' Het meisje knikte. 'Noem het paard Tabula, dat betekend blad. Want je hebt een Tabula Rasa in je handen, een onbeschreven blad.' Dat beloofde het meisje.

Eenmaal thuis aangekomen, begon het meisje voorzichtig te schrijven op Tabula. In het begin wilde ze alles in een keer goed opschrijven. Ze wilde voorkomen dat ze woorden door moest strepen, want dan zou Tabula niet worden als de paarden van de koetsier. Dus schreef ze woord voor woord, maar al na de eerste zin had ze wat foutjes gemaakt. Dat vond ze heel erg. Ze probeerde met haar tranen de fouten uit te vegen, maar stopte daar al snel mee, want de fouten veranderden in lelijke vlekken. Dus schreef ze over de fouten heen, laag over laag. Hoewel ze af en toe wanhopig was, omdat ze niet meer wist hoe ze verder moest schrijven, deed ze Tabula niet weg. Ze vond het juist wel mooi als ze een nieuw woord over het oude woord heen schreef en ze het oude woord nog er nog doorheen kon zien. Als ze echt niet meer wist hoe ze verder moest, liet ze plekken leeg, om ze op een later tijdstip in te vullen. Ondertussen schreef ze dan verder aan andere zinnen. Langzaam begon haar beeld van hoe Tabula er uit moest komen te zien te veranderen. Tabula moest lijken op de paarden van de koetsier, maar Tabula moest ook op haar lijken.

Op een ochtend, vele jaren later, liep het meisje zoals iedere morgen naar de bosrand en fluisterde zachtjes 'Tabula'. Eerst was het stil, maar opeens hoorde ze het aanzwellende geluid van hoeven die krachtig de grond *raakten. Tabula rende in vliegende vaart het bos uit, maakte een sierlijke bocht en kwam abrupt voor haar tot stilstand. Het zand vloog haar om de oren en ze moest giechelen, omdat het kriebelde. Tabula boog zijn sierlijke hals en hinnikte zo hard dat hij het stof uit haar ogen blies. Toen ze haar ogen opende zag ze dat Tabula gitzwart was geworden. Alle woorden en zinnen waren in elkaar opgegaan en verdwenen.*

De parallellen tussen dit sprookje en het promotie-traject zullen je niet ontgaan zijn. Promoveren is een lange bochtige weg door bergen en dalen. Het vereist geduld, doorzettingsvermogen, zelfreflectie en zelfstandigheid. Een proefschrift schrijf je naar eigen inzicht, maar binnen de bestaande kaders. Je maakt fouten, maar daar leer je van. Het resultaat is altijd anders dan je van tevoren had bedacht, maar uiteindelijk komt alles samen tot een compact geheel. De details en het geploeter worden langzaam onzichtbaar en de oorspronkelijke contouren komen uiteindelijk weer te voorschijn.

Door de jaren heen hebben veel mensen, dieren, planten en zelfs elementen bijgedragen aan dit boekwerk. Soms was het een begeleider, een collega, een student, een boer, een familielid of een vriend. Maar vaak ook een kip of een paard of gewoon de wind in mijn haren. Al die hulp is omgevormd tot een compact en egaal geheel. Ergens in dit boekje kan iedereen die ik in de afgelopen jaren ben tegen gekomen zichzelf terug vinden. De volgende 'Tabula Negra' is opgedragen aan dit geheel van invloeden.

[redacted]

About the author

Curriculum vitae

Sanne Dekker was born on the 29th of August 1978 in Leiderdorp. She attended secondary school at the Coornhert Gymnasium in Gouda. After receiving her VWO diploma in 1997, she started her study Animal Science at Wageningen University. She specialized in Animal Production Systems (major thesis) and Rural Sociology (minor thesis). She executed her major thesis at the Institute of Organic Agriculture of the University of Natural Resources and Life Sciences in Vienna. The topic of this thesis was ecological footprint of organic suckling beef and conventional fat stock beef in the region Mostviertel-Eisenwurzen (Austria). Her minor thesis focussed on identification of indicators for specific taste of regional products. As an intern she focused on nomadic animal husbandry at the University of Agriculture in Ulaan Bataar (Mongolia) and on research on organic farming at the Louis Bolk Institute in Driebergen. She graduated in 2003.

Between 2003 to 2007 she took part in several projects (organic farming, animal welfare, and biogas production) for the University of Natural Resources and Life Sciences in Vienna and Wageningen University. In 2007 she started a PhD with the theme ecological sustainability of the organic egg production chain. This project was a cooperation between the Farm Technology Group, the Animal Production Systems Group, and Livestock Research of Wageningen University and Research Center. Since October 2011 Sanne works at LEI Wageningen University and Research Center for The Sustainability Consortium.

Publications

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COMPLETED TRAINING AND SUPERVISION PLAN

Sanne E. M. Dekker

Description	**Institute**	**Year**	**ECTS**
Research Skills Training			
Preparing PhD research proposal		2007	6.0
In-Depth Studies			
Science meets society, feed, food and fuel	WIAS	2007	1.5
Uncertainty analysis	SENSE	2008	1.0
Design of animal experiments	WIAS	2008	1.0
Poultry discussion group	WIAS	2007-2011	0.6
Life cycle assessment discussion group	ASG-APS	2007-2011	0.3
Self study: reading and learning LCA theory		2007	1.6
Professional Skills Support Courses			
Presentation skills	WGS	2007	1.9
Introduction course	WIAS	2007	1.5
Workshop career coaching	WIAS	2007	0.2
Afstudeervak organiseren en begeleiden	OWU	2007	0.8
Competence assessment	WIAS	2007	0.3
Ethics and philosophy in animal sciences	WGS	2010	1.5
Scientific writing	WGS	2010	1.2
Talent day, Utrecht.	NWO	2010	0.3
Didactic Skills Training			
Excursions Lankerenhof, Voorthuizen, 22-06-07		2007-2008	0.6
Supervision BSc and MSc-theses		2007-2009	3.0
Lectures for course Livestock Technnology		2007-2010	1.0
Tutorship for course Boerderijproject		2008	0.6
Lectures for course Problem Exploration Agrotechnology		2008-2011	0.6
Scientific Exposure			
Symposium technology and animal welfare, Wageningen.		2007	0.2
Poultry and people seminar, Wageningen.		2007	0.2
Sustainable agriculture and soy congress, Wageningen.		2007	0.3
Bioland international poultry congress, Almen.		2007	0.6
KTBL 8. Tagung Bau Technik und Umwelt 20007, Bonn, Germany.		2007	0.3
LCA Food Conference, Zurich, Switserland (incl. oral presentation).		2008	1.6
JIAC, Wageningen (incl. oral presentation).		2009	1.9
AgEng 2010 Conference, Clermont-Ferrand, France.		2010	0.9
LCA Food Conference, Bari, Italy.		2010	0.6
WIAS Science Day, Wageningen, (incl. oral and poster presentation).		2008-2011	2.0
Total (minimum 30 ECTS)			**33.9**