Organic Broilers
in Floorless Pens on Pasture

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Abstract

Bassler A. W. *Organic Broilers in Floorless Pens on Pasture*

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This thesis investigates different aspects of rearing broilers organically in floorless pens on pasture. The birds and pens were moved daily to fresh pasture. The interdisciplinary studies comprise the birds' growth performance and carcass quality, health, behaviour, leg condition and the birds' effect on pasture. In the final study, on-farm diets were tested in a feeding experiment indoors.

The data are based on four experiments carried out during 2000 to 2003.
In 2000 and 2002, restricted-fed conventional broilers (ROSS 208) were reared in floorless pens on pasture and in control groups outdoors on straw.
In 2001, two genotypes, ROSS 208 and the slow-growing ISA 657 were reared on three ground types, pasture, outdoors on straw and indoors on wood shavings with either an *ad libitum* or restricted feeding level.
In 2003, a feeding experiment with slow-growing broilers fed on-farm diets in a choice feeding system was conducted indoors.
Most birds were reared to 12 weeks of age, but *ad libitum*-fed ROSS birds were reared to 6 weeks. The experimental phase was from ca. 3 weeks to slaughter.

The experiments indicate that under the given conditions

- access to pasture does not offer sufficient protein and metabolizable energy to allow considerable feed savings in the farm enterprise (Paper I)
- moving the floorless pens daily provides favourable conditions to prevent infections with C*ampylobacter* and *Eimeria* in outdoor broilers (Paper II)
- access to pasture as such appears to play no major role for the broilers' physical activity (Paper III) or leg condition (Paper IV)
- broiler chickens on pasture can sustain white clover in a mixed grass/white clover pasture (Paper V)
- with access to high-quality protein during the first three weeks there is a good potential to produce organic broiler meat with feed produced on-farm in northwestern Europe (Paper VI).

Keywords: behaviour, botanical composition, *Campylobacter*, coccidiosis, leg condition, on-farm diet, organic agriculture, pastured broilers

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Papers I-VI

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. *Bassler, A.W., Elwinger, K., Kwakkel, R.P. & Ciszuk, P.*

Rearing broilers in floorless pens on pasture:
I. Effects on growth performance and carcass quality.
(Manuscript)

II. *Bassler, A.W. & Hansson, I.*

Rearing broilers in floorless pens on pasture:
II. Effects on the occurrence of coccidiosis, Campylobacter and Salmonella. *(Manuscript)*

III. *Bassler, A.W., Presto, M., Elwinger, K. & Keeling, L.J.*

Rearing broilers in floorless pens on pasture:
II. Effects on the birds' behaviour.
(Submitted)

IV. *Bassler, A.W., Berg, C. & Elwinger, K.*

Rearing broilers in floorless pens on pasture:
IV. Effects on the condition of the birds' legs and feet.
(Submitted)

V. *Bassler, A.W., Ciszuk, P. & Frankow-Lindberg, B.*

The effect of broilers reared in floorless pens on pasture on the botanical and chemical composition of the pasture.
(Manuscript)

VI. *Bassler, A.W., Kwakkel, R.P., Elwinger, K. & Ciszuk, P.*

Performance of slow-growing broilers given on-farm diets in a choice feeding system.
(Accepted, Biological Agriculture & Horticulture)

General introduction

Historical background

Poultry production in the industrialized countries has changed significantly during the past 75 years; from pastured flocks of dual-purpose breeds fed on-farm diets and kept for eggs as well as meat production (Oden, 1994), to specialized industrial production systems (DeHaan *et al.*, 1997), depending on outside inputs and based on large economies of scale.

After World War II, the advances in animal nutrition, breeding, veterinary science and mechanization and automatization, together with increasing labour costs, fuelled the process to specialize and intensify* agricultural production. Today, industrial broiler production is a system that has achieved a high meat yield:cost ratio (costs on farm enterprise basis). The product output per animal and time unit can be used to give an indication of the development realised during the past decades. Between 1957 and 1991, the age to reach a 1500 g-body weight and the amount of feed required to achieve this has been more than halved (Havenstein *et al.*, 1994). A similar comparative study conducted 10 years later (years 1957 to 2001) showed that this trend is continuing (Cheema *et al.*, 2003). Similar developments can be observed in different farm animal species (Rauw *et al.*, 1998).

This high increase in yield was a great success both in zootechnical terms and in terms of human food supply. The U.S. per capita consumption of broiler meat has risen from about 4 kg in 1950 (Tarver, 1986) to over 30 kg in 1990 (Perez *et al.*, 1991). However, the continuing intensification in agriculture substantially contributed to broiler welfare problems (SCAHAW, 2000, Whitehead *et al.*, 2003), environmental pollution (Oomen *et al.*, 1998; Statistics Sweden, 2004) and loss of ecosystem services (Björklund *et al.*, 1999). At the same time, the increased standard of living gave the human food supply a relatively lower priority in the industrialized countries (Wegner, 1982). With time, society began to increasingly concern itself about the sustainability of modern conventional agricultural practices (WCED, 1987; UNCED, 1992).

Conventional, sustainable and organic agriculture

The numerous existing definitions of 'sustainability' all emphasize the need to simultaneously care for the ecological, economical and socio-ethical consequences of development choices for present and future generations (Gibon *et al.*, 1999). In conventional agriculture economical performance is emphasized to survive on the market and to remain competitive. Intensification of agricultural production contributes to keep the costs on farm basis (farm-internal costs) low. But costs

* *Intensity is defined here as output of a specific agricultural product (e.g. kg wheat or milk) per production unit (e.g. land area or cow).*

arising from unsustainable agricultural practices such as pollution of ground- and surface waters, are not or not-fully reflected in the farm's financial balance. These costs may be unaccounted for or not related to the production on farm (farm-external costs). In a sustainable production system, all costs and benefits of agricultural practice are to be considered (Tilman *et al.*, 2002). These costs and benefits would also include socio-ethical issues such as animal welfare (Lund & Röcklinsberg, 2001; Morton, 2004).

Typically, but not always, the realization of ecological and socio-ethical goals results in lower product output per animal, stable capacity or land area unit than in more intensive agriculture. As a consequence, the market price often has to be higher to be equally profitable in today's economic system. This in turn weakens the competitive market position of sustainable agricultural production.

Measures to enhance sustainability can be varying and which one is the most appropriate depends on the point in time and place, where the choice has to be made (Schiere & Rickert, 2004). Partly there is little consensus on which measure to choose or to what degree. The EU regulation for organic agricultural production (EC, 1999) is a comprehensive set of measures that aims to create a framework for sustainable crop and animal production. In most cases, the regulations for organic farming are more stringent in requirements for ecological and socio-ethical goals than the local country's national laws, ordinances and regulations for animal welfare, food safety and environmental protection. In 2001, the European Action Plan for Organic Food and Farming was initiated to facilitate the development of organic farming. Here, the Commission of the European Communities recognizes organic agriculture as "an important device towards the attainment of environmentally friendly, quality products" (EC, 2004). But not all of today's organic agriculture practices fulfil the sustainability goal and therefore need to be developed (e.g. leaching of nitrogen to the ground water following the ploughing of grass/clover leys (Lampkin, 1990) or feather pecking in laying hens (Berg, 2001).

When practically feasible and economically viable, organic farm enterprises challenge the conventional mainstream. Organic agriculture may then serve as a pioneer movement, providing experiences that might be of value to the current process of developing sustainable agricultural practices for the majority of farms. Seen it this way, organic agriculture is a way to develop sustainable agriculture on a time axis rather than being an ultimate solution to the undesired side effects of today's conventional agriculture.

The concepts of conventional and organic agriculture

Modern life science and conventional agricultural research are based on the worldview that nature can basically be analyzed quantitatively and is governed by natural laws (materialistic/mechanistic worldview, cf. Newton, 1668). With this worldview, the human being, for example, is regarded as "… an automaton, and the fact that we are sensing, feeling and knowledgeable beings is part of this automatic sequence of life," as quoted in Guyton & Hall (1996). This worldview is strongly related to the view that a research object can best be understood by dividing it into its components and investigating these separately (reductionism, cf. Descartes, 1596–1650; Cottingham *et al.*, 1984). Consequently, conventional agricultural research has long been characterized by investigating the direct link between an observed effect and its hypothesized cause i.e. "the effect of x on y." This approach has been the foundation of the western world's biological and technological progress during the past 200 years, including agriculture. However, the reductionistic approach appears to bear the risk that the parts are investigated at the cost of the attention to the whole and it has been criticised that the reductionistic approach is not sufficiently effective in controlling the undesired side-effects of conventional agriculture, e.g. environmental pollution (McRae *et al.*, 1989).

Organic agriculture is based on a worldview that can be called "holistic" (Merrill, 1983). In contrast to reductionism, holism focuses on the whole. The approach implies that wholes, for example agro-ecosystems, are more than the sum of their elements, and elements lose certain properties when their relationships with other elements are ignored (Hill, 1982). Because it is not possible to consciously take all elements and levels of organisation (e.g. cell, organism, farm, region, biosphere) of the whole into account, organic agriculture may have a metaphysical or spiritual dimension (cf. Steiner, 1924). Also social questions, and thus values, such as concern for rural communities or fair trade, are components of organic agriculture (IFOAM, 2002).

Due to the association of the materialistic worldview with natural science on the one hand and the holistic/organic worldview with spiritual and social, - 'ideological' issues on the other, the question may arise how scientists should handle values in their work and "… still be scientific." (cf. Alrøe & Kristensen, 2002).

Kuhn (1970) elaborated that all researchers largely build their work upon a body of beliefs - a paradigm - defined as a matrix of key theories, values and metaphysical assumptions (Bird, 2005). Kuhn argues that meaningful collection of data (facts) is actually dependent upon relating these data to a paradigm: without paradigm, everything would be equally relevant and it would not be possible to assign priorities to certain research questions. Kuhn concludes that, when scientists collect and interpret their results, "… more than mere facts are at hand". According to Kuhn, then, both conventional and organic agricultural methods and all related research would be based on different paradigms. If science is always based on paradigms or worldviews, then labelling conventional and organic agriculture as "scientific" or "ideological" does not correctly describe the underlying differences between these two forms.

The following section describes the perception of the farm and agricultural production according to both the mechanistic/reductionistic worldview and the organic/holistic approach.

With a mechanistic worldview a farm could be compared with a machine. This would emphasize that the farm is man-made and its primary purpose is agricultural production. Consequently, the organisation of the farm should facilitate maximized production. The farm is often specialized in one type of production. The farmer dominates nature and controls the means of production (e.g. by using embryo transfer and gene technique). Technological advancements such as precision agriculture (Coulson, 1992) and highly-developed external inputs such as crystalline amino acids or coccidiostatics are means to achieve the desired output. Negative side effects are eliminated were they arise and with minimum impact on production. Organizational differences between farms within a region are deviations from an economic optimum.

In organic agriculture the farm is often likened to an organism, which means that it is a living entity (a whole), a part of nature. The definition further implies that the farm (or agro-ecosystem) is composed of sub-elements ("organs": including soil, crops, farm animals, wildlife etc.). The word "organic" in organic agriculture originates from this concept (Scofield, 1986). A balance or 'harmony' (IFOAM, 2002), within and among these organisms, is necessary for the production on the farm as a whole. The central organ of each farm is the soil. The farmers acknowledge the necessity of interaction and balance between these 'organs' on the farm and therefore there is a diversification of the farm organization. The farmer cannot control nature but has to cooperate with her. Agricultural production is facilitated by support of desired natural processes. External inputs should not interfere with the system's ability of self-regulation. Undesirable side effects are regarded as indicators of imbalances in the agro-ecosystem. Each farm is characterized by individual conditions, including the farmer, and organized accordingly.

Organic farming practice is guided by rules, principles and aims as formulated in the Basic Standards of the International Federation of Organic Agriculture Movements (IFOAM, 2002), founded in 1972, and for the European Union as written in EU Regulation No. 1804/1999 (EC, 1999).

The differences between conventional and organic agricultural practices are thus significant and the starting points are profoundly different and can even be in direct conflict.

However, the definitions of these two farming methods are not clear-cut (Alrøe & Kristensen, 2002) and elements that seem to be typical for organic agriculture may appear in varying degrees in the many forms of conventional agriculture. For example conventional agriculture practices often include some form of crop rotation and the use of animal manure as crop fertilizer. Organic agriculture practices include the use of conventional, high-yielding farm animal genotypes (e.g. for milk and egg production) and the specialization of the farm organization. Further, both conventional and organic methods undergo continual developments.

Although there do exist 'alternative research methods' in organic agricultural research, as for example 'copper chloride crystallisation' (Koenig, 2002) or 'phenomenology', described in Smith (2003), research in organic agriculture is predominantly conducted with the same research methods as research in conventional agriculture, and with the same policy of keeping the subjective element out of experimentation, observation and technical procedures to the greatest possible extent. - The difference lies in the basic framework that is the starting point for defining the research goals and the subsequent appraisal of priorities.

Conventional and organic broiler production

The requirements for organic broiler production, as written in EU Regulation No 1804/1999, can be summarized as follows:
- Use of slow-growing genotypes
- Use of farm-own feed
- No use of preventive allopathic veterinary medication
- Access to pasture
- Relatively low stocking density, compared with conventional systems

In many cases, organic agricultural practices can be well explained in contrast to undesirable side effects of conventional agriculture. The use of slow-growing genotypes and the use of farm-own feed shall be taken as examples:

Slow-growing genotypes in organic agriculture

Broiler growth rate is negatively related to feed:gain ratio (feed intake per unit deposited tissue) and both factors are key elements to maximize meat yield:cost ratio (Walker, 2001).

Conventional broilers are usually raised to five to six weeks of age, with a mean daily weight gain of 50–60 g (Anonymous, 2004; Aviagen, 2004). As a consequence of the selection for high-growth rate and low feed:gain ratio, the musculo-skeletal system (e.g. of the legs) and some so called ‘energy-supplying organs’ (e.g. the cardiovascular system) do not develop in proper relation to serve their functions (Decuypere & Verstegen, 1999; Whitehead *et al.*, 2003). Between 5–30% of today’s flocks may have leg disorders of a severity that the bird’s welfare is compromised (gait score >2 from Kestin *et al.*, 1992; Sanotra & Berg, 2003). Ascites, which reflects chronic heart failure, can increase flock mortality by up to 2% units at low altitudes and more at high altitudes (Savory, 1995; Butterworth, 2004). According to Julian (2004), sudden death syndrome (acute heart failure, heart attack) may be the cause for the death of 2–4% of the male birds in "good flocks". These and other diseases related to fast growth are sometimes grouped under the term 'metabolic disorders' (Julian, 2004). Scheele (1997) points out that only some of the birds that suffer from metabolic disorders die before slaughter day and concludes that the effects on broiler welfare is much higher than can be derived from the mortality rate.

Broiler parents have a similar growth potential as their progeny (Savory, 1995; Hocking, 2004). Fed *ad libitum*, egg production and hatchability would be poor and mortality high, due to metabolic disorders (Hocking *et al.*, 2002). Feed allocations during rearing are 60–80% less than birds would consume *ad libitum*, and are 25–50% less during the laying period (Yu *et al.*, 1992, Savory *et al.*, 1993). Broiler parents on commercial-restricted rations tend to show stereotyped pecking behaviour at non-food objects, overdrinking or excessive preening (Savory & Maros, 1993) and increases in the heterophil:lymphocyte ratio and the portion of basophilic cells in the blood, recognized as indices of physiological stress (Hocking & Maxwell, 1993).

Further, there are indications that physiological and immunological stress in broilers with high growth rates makes these birds more sensitive to infectious diseases (Yunis *et al.*, 2000, Lamont *et al.*, 2003). From other studies it was concluded that the genetic and possibly nutritional changes have put faster growing broilers in a disadvantageous situation in terms of humoral immune function (Koenen *et al.*, 2002).
In organic agriculture, slow-growing genotypes should therefore be used to avoid specific diseases or health problems associated with intensive production, as described above (IFOAM, 2002).

Farm-own feed

Establishment of specialized crop and livestock farms and the concentration in different regions has geographically separated animal manure production from crop production. In the most specialized regions with animal production, animal manure became a waste product for disposal instead of being a valuable local resource of plant nutrients and soil organic matter. In 1997, The Netherlands, Brittany (in France) and Denmark depended on 85, 40 and 20%, respectively, of feed imports for their intensive pig and poultry industries. Consequently, large quantities of manure had to be transported to “manure deficit” areas. The transportation distance rose up to 100 km in the Netherlands, an average of 15 km in Brittany, whereas in Denmark, almost all manure could be applied in the immediate surrounding area (DeHaan *et al.*, 1997). It has been shown that regional excess of animal manure production reduces the efficiency of manure as a crop fertilizer in the regional agro-ecosystem (Oomen *et al.*, 1998), and that a re-integration of animal and crop production results in a considerable reduction of nutrient losses (Cederberg, 2002, Lantinga *et al.*, 2004).

In organic agriculture, all animal feed should therefore be produced on the farm itself or within the region (IFOAM, 2002), which determines the number of animals that can be kept in a region.

Problem solving: systems and reductionistic approach

The problems described above are specifically associated with intensive and specialized production. In organic broiler husbandry metabolic disorders, abnormal behaviour, immunodeficiency and nutrient losses or fossil fuel used for manure transportation over longer distances would be regarded as indicators of imbalance in the "organism", the regional or farm ecosystem.

It has earlier been indicated that the organic approach and the system approach are closely related. The systems approach evolved independently of organic agriculture (Bertalanffy, 1968, Sands, 1986, Schiere *et al.*, 2004), however, both emphasise more holistic than reductionistic approaches. Instead of interpreting the above mentioned problems as imbalances in the organism, the system approach would define these as side effects that are more or less systemic in nature, i.e. the effects are linked to each other and/or to the performance of the conventional broiler production system as a whole that has the primary goal of economically viable meat production.

The more systemic the nature of undesired side effects, the more questionable it becomes how effectively they can be tackled when they are treated individually as they arise (reductionistic approach). The system approach then promises to be more effective in identifying the problems and addressing the causes by taking into account the relationships between the elements involved (Conway, 1985). Changes on system level may have implications elsewhere in the system in contrast to limited, ‘precision’ measures. The two examples outlined below, 'leg disorders in broilers' and 'nutrient losses from manure to the environment' illustrate this.

Example 1. Leg disorders in broilers

Leg disorders in broilers are a consequence of genetic selection for high growth rate (Whitehead *et al.*, 2003). Use of slow-growing genotypes extensively reduces leg problems (Kestin *et al.*, 2001). On the other hand, slow growth also implies reduced meat production rate and a higher feed:gain ratio: Van Harn & Van Middelkoop (2001) found that an extension of the growing period to 2.2 kg from 42 to 56 days increased the costs on farm by 10% per bird and 10–15% for the white meat.

An example of a more reductionistic approach to this problem would be to focus on specific ways to suppress the abnormal cell death in the tibial growth plate, a symptom for tibial dyschondroplasia (TD) (Weaver, 1998). However, the development of such a treatment is time consuming and its effect is likely to be limited to TD, whereas the other side effects of fast growth need to be treated separately. Suppression of the cell death might be suppressed with an industrial feed supplement, but this would increase the farms' dependence on external inputs.

Example 2. Nutrient losses from manure to the environment

Regional specialization of animal production finally leads to an excess of animal manure in relation to regional crop production which reduces its efficiency as a crop fertilizer in the regional agro-ecosystem. (Oomen *et al.* 1998). In organic agriculture, all animal feed should therefore be produced on-farm or within the region (IFOAM, 2002), which determines the number of animals that can be kept in a region. But it also reduces the possibilities to take financial advantage of trade with feedstuffs.

A more reductionistic approach to this problem (nutrient losses) would be for example to optimize the protein quality in the diet with synthetic amino acids supplements. Under precise feeding conditions this can minimize the animals’ N excretion by up to 20–40% (Verstegen & Jongbloed, 2003), without reducing animal production performance or affecting farm organization. However, the excretion of other nutrients, e.g. phosphorus, is not reduced by supplementation of amino acids in the same order of magnitude and may have to be dealt with separately. And also here, this strategy would increase the farms' dependence on external inputs.

Starting point and concept

Starting point

The European standards for organic animal husbandry aim to achieve the use of 100% organic feed (EC, 1999). In 1999, the Swedish Board of Agriculture announced that the study of mixed animal husbandry systems would be a field prioritized for research (Frid, 1999). The starting point for experimental design of the present project was broiler nutrition in organic agriculture, with special attention to the nutritional contribution of pasture (Papers I & VI). Regarding pasture as a part of an on-farm diet for broilers led to the idea of studying the interaction between broilers and pasture, the behavioural effects of access to pasture and the effect on subsequent leg condition (papers III & IV), and the broilers' effect on the botanical composition of the pasture (paper V).

Paper II was motivated by the findings of a Danish study that found all studied organic broilers in the country *Campylobacter*-positive and related this finding to the fact that these birds had all access to outdoor ranges (Heuer *et al.*, 2001).

Coccidiosis was monitored to be able to see whether the parasite might have affected growth performance in the different treatments. *Salmonella* was monitored primarily for reasons of food safety.

The relevance of the selected research areas was later confirmed by a Dutch investigation by Rodenburg & van Harn (2004) that identified the following fields in need of further development for organic broiler husbandry:
- Prevention of coccidiosis, *Campylobacter* and *Salmonella*
- Composition of feed rations with 100% organic ingredients
- Information about mobile housing
- Design of the outdoor range
- Comparison of slow-growing genotypes

Concept behind the studies

The concept behind the present studies with broilers in floorless pens is a mixed agricultural production system with pastured poultry and cattle as described by Ciszuk (1999, Figure 1). 'Mixed' in this context implies the use of different animal species in a common grazing system, whether or not the species graze the same area of land at the same time (cf. Hodgson, 1979).

As McNaughton (1976) showed for Serengeti migratory wildebeest, the grazing of different species facilitated grazing and improved grassland productivity, Nolan & Conolly, 1977 and Nolan, 1992 have shown that also mixed grazing systems with cattle and sheep are more feed-resource efficient than mono-grazing systems. Mixed systems were further less susceptible to disease than mono-grazing systems (Nolan & Conolly, 1977). A study of a mixed grazing system with heifers and sows had comparable results (Sehestedt *et al.*, 2000).

Ciszuk (1999) describes a design to develop ecologically beneficial interactions between cattle and poultry on pasture and farm level. The papers included in this thesis focus on broilers for meat production.

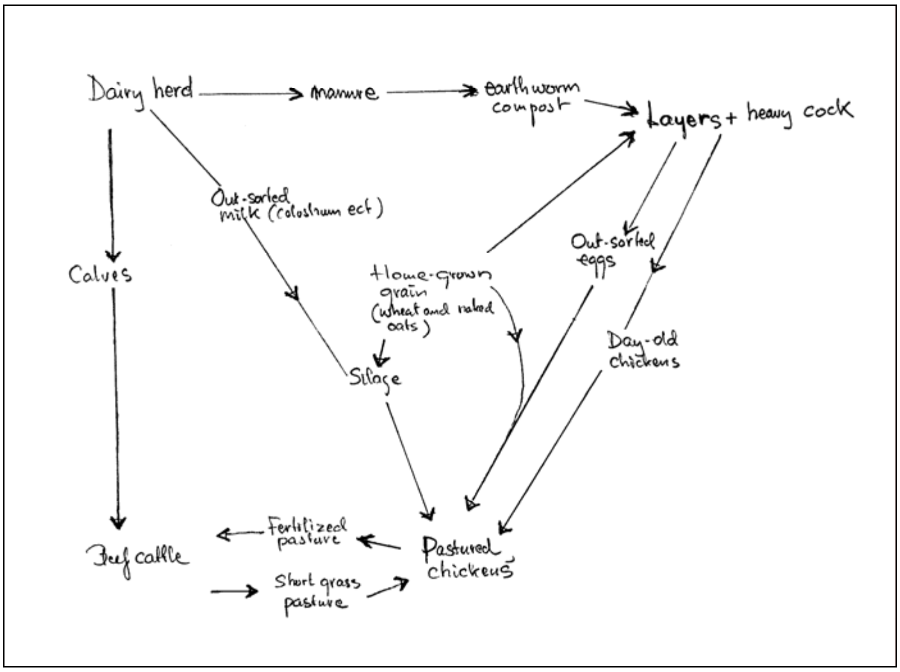

Figure 1. Diagrammic illustration of a mixed farming system with cattle and pastured chickens, scetching potential links between animal species and on-farm feed (Ciszuk, 1999).

Grass is a common component in the diet of wild chickens (Savory *et al.*, 1978). However, grass is hardly the main source of energy and protein in wild or domesticated chickens. Together with a rotation of the birds on pasture to sustain bird health, chickens consume only a minor part of the herbage production on pasture (Bassler *et al.*, 2000). The majority of pasture is for the cattle (or other ungulates). Cattle grazing creates a pasture with short grass, which is beneficial for poultry (Thaer, 1990). Potentially, waste products of milk or whey and earthworm compost may be available as chicken feed. The pastured chickens' manure fertilizes the grassland. In the present study this system remains itself "hidden" behind the experimental scenery. However, it is the basis to each experiment.

The work as a whole is interdisciplinary. Papers I to IV concern the birds' zootechnical performance, behaviour and health on pasture. Paper V looks at the broilers' effect on pasture and paper VI investigates the performance of broilers fed on-farm diets.

These studies do not describe an agricultural system as a whole, as for example the studies of Coppock (The Borana Plateau of Southern Ethiopia, 1993) or Strid Eriksson (Environmental Systems Analysis of Pig Production, 2004). Nor do they focus on a key element, as for example the studies of Waldenstedt (Coccidial and clostridial infections in broiler chickens, 1998) and Berg (Foot-pad dermatitis in broilers and turkeys, 1998). Instead, selected topics from different disciplines were investigated to gather specific information about aspects of the floorless pen system, and about organic broiler production in general.

Socio-economic and meat quality aspects are not covered in the present project.

Aims of the thesis

The main objective of the work presented was to contribute to the development of husbandry systems for organic broilers in Sweden from the perspectives of animal nutrition, management and health. All studies except the feeding experiment presented in paper VI were conducted with the floorless pen system.

The specific aims of the thesis were to study

- The nutritional contribution of pasture to the broilers' diet (paper I)
- The occurrence of coccidiosis, *Campylobacter* and *Salmonella* in pastured broilers (paper II)
- The effect of pasture on the broilers' behaviour and leg condition (papers III & IV)
- The broilers' effect on the pasture's botanical composition (paper V)
- The effect of feeding a low-methionine diet with on-farm ingredients on diet selection, feed intake, growth and carcass characteristics (paper VI)

Summary of Materials & methods and Results (Papers I-VI)

Summary of Materials & methods (Papers I-VI)

The data are based on four experiments conducted between 2000 and 2003.

In 2000 and 2002, conventional broilers (ROSS 208) that were on restricted rations were reared in floorless pens on pasture (PAST) and the control groups were reared outdoors on straw (STRW).

In 2001, the experiment included three ground types, PAST, STRW and indoors on wood shavings (INDO); two genotypes, ROSS 208 and ISA 657 (slow-growing genotype); and two feeding levels, *ad libitum* or restricted.

Figure 2 shows a drawing of a floorless pen used in the present experiment. A detailed description of it can be found in paper III.

In 2003, a feeding experiment with slow-growing broilers fed diets with different methionine levels in a choice feeding system was conducted indoors. Four diet treatments were administered from day 22 to 81: (1) a concentrate of ingredients that can be produced on-farm in northwestern Europe plus whole wheat, in a choice feeding system (FARM); (2) as (1), but crystalline methionine and lysine added to the concentrate (FARM+); (3) a concentrate of conventional ingredients plus whole wheat, free choice (CONW); (4) as (3), but all wheat ground and included in the concentrate, no free choice (CTRL).

Most birds were reared to 12 weeks of age, but *ad libitum*-fed ROSS birds were reared to 6 weeks. The experimental phase was from ca. 3 weeks to slaughter.

Growth performance (weight gain, feed conversion ratio and mortality) was measured in all experiments. The effect of pasture on the birds' chemical composition at slaughter was measured in 2002. Carcass yields and weight of organs were measured in 2002 (effect of ground type/pasture) and 2003 (effect of diet/on-farm diet).

Also in 2003, choice feeding of whole wheat and concentrate was studied weekly.

The occurrence of *Salmonella*, *Campylobacter* and coccidiosis was monitored at different ages between 3 and 12 weeks of age during 2001 and 2002.

In 2001, all treatment groups were studied for their behaviour, especially physical activity, and the condition of legs and feet, both at 5 and 11 weeks of age.

The effect of broilers on the botanical and chemical composition of the pasture in the autumn of the year of grazing and in the spring of the following year was studied for all pasture experiments (2000–2001).

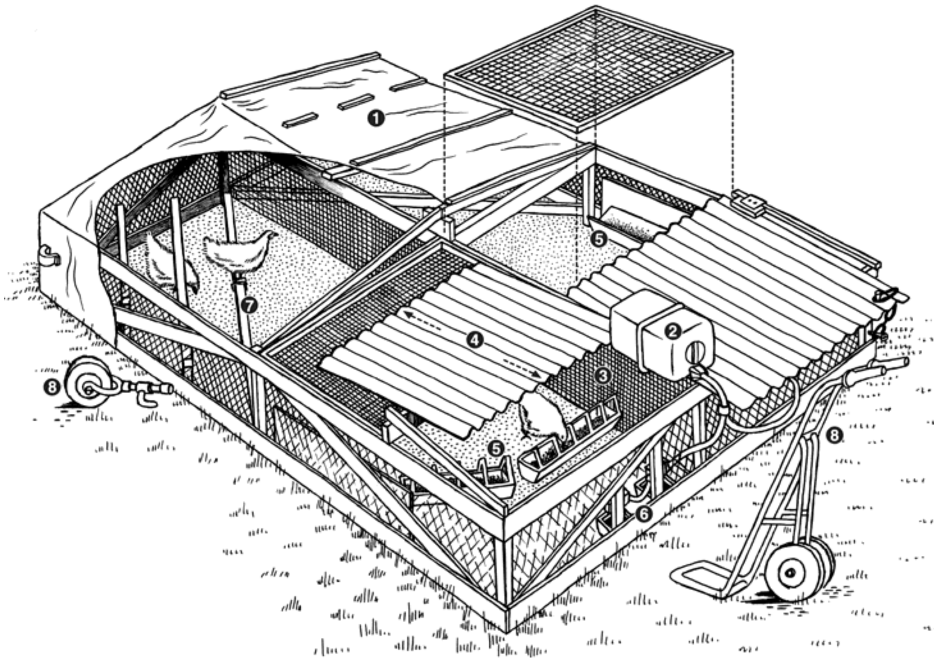

Figure 2. Drawing of a floorless pen, 3.30 wide x 4.00 x 0.65 m, containing 2 experimental groups. Both pen-halves are designed identically.

(1) Rear half furnished with water resistant cardboard.
(2) Tank for drinking water.
(3) Wire net, dividing the pen along the longitudinal axis.
(4) Roofs, covering feeders and drinkers, slide under water tank.
(5) 3 Feed troughs, 350 cm feeder space per group.
(6) 2 Drinkers, each 13 cm wide, per group.
(7) 3 Perches, 5 m total length, per group.
(8) Set-up to move the pen: One wheel attached at each rear corner, trolley hooked to the front side.

Summary of Results (Papers I-VI)

Growth performance on pasture (paper I) showed that *ad libitum*-fed Ross 208 birds outdoors on straw and indoors had significantly higher body weight gains and carcass weights than those on pasture in 2001. *Ad libitum*-fed ISA birds outdoors on straw and indoors had significantly higher carcass weights than on pasture.

The restricted-fed ROSS 208 birds performed differently in the different experimental years. In 2001, birds on pasture and indoors both grew significantly faster than outdoors on straw. In 2000 and 2002, the housing environment did not affect growth rate significantly. Differences in relative weight of breast meat, wings or thighs between birds raised on pasture or straw were negligible (restricted-fed ROSS 208 birds, measured in 2002).

Paper II examined *Campylobacter*, coccidiosis and *Salmonella*. *Campylobacter* were found only in broilers outdoors on straw in samples taken from the cloaca. At the abattoir, neck skin samples revealed *Campylobacter* also in those groups that had entered the processing line after the groups from outdoors on straw. Levels of *Eimeria* oöcysts in the faeces were low in all groups. *Salmonella* was not found in any of the groups.

In Paper III, the focus was on behaviour. Ground type did not affect behaviour that could be seen as a reaction to stimuli from the ground (e.g. scratching or ground pecking). Birds kept indoors preened more than birds kept outdoors. ISA birds perched more than ROSS birds. *Ad libitum*-fed ROSS birds spent more time lying than birds in any other treatment. Feed restriction of ROSS birds increased the time spent standing idle, preening, drinking and ground pecking.

Paper IV examined the condition of legs and feet. The *ad libitum*-fed ROSS birds had a considerably higher gait score indicating a worse leg condition at 5 weeks of age than any other group at 5 or 11 weeks. There was no significant effect of ground type on gait score at 5 weeks of age whereas the different 'genotype × feed' combinations and the bird's sex both significantly affected gait score. At 11 weeks of age, restricted-fed ROSS birds on straw had higher gait scores than the birds on pasture or indoors, whereas this was not the case with *ad libitum*-fed ISA birds.

Varus/valgus deformities were predominant in the groups outdoors on straw (17–22% at 11 weeks), probably due to poor litter quality, and were found in all of the *ad libitum*-fed ROSS groups (17–25% of the birds at 5 weeks of age). Also findings of foot-pad dermatitis were localized to the groups outdoors on straw (12–45% of the birds).

The effect of broilers on pasture was studied in Paper V. Broilers increased the crude protein content of the herbage measured in the autumn, but the increase was not evident in the following spring compared with the control. Sward height in the autumn was lower after broilers than in the control. The proportion of clover after broiler grazing was lower than in the control in the autumn, but in the following spring, there was a higher proportion of clover compared to control.

Paper VI examined farm-own feed: The birds in the choice-feeding systems consumed less whole wheat and more concentrate — and thus more crude protein — than expected. Access to grit stones reduced feed:gain ratio and increased the intake of whole wheat in CONW.

The birds on FARM showed signs of compensatory growth but neither these birds nor those on FARM+ reached the body weight of the birds on the two diets with conventional ingredients at slaughter.

There were no differences among treatments in relative breast meat yield or in percent of the weight of the skinned carcass.

General Discussion

The experiments with broilers in floorless pens on pasture showed that the pens moved daily can help to prevent *Campylobacter* and coccidiosis infections and that the pastured birds sustained the white clover in the pasture. These studies showed further that both the nutritional contribution of the pasture and the effect of access to pasture on the birds ' physical activity and leg condition was negligible. The frequency of the movement of the pen, the number of birds per pen and the fact that the birds were confined in the pen were all factors that determined stocking rate in space and time. This probably affected all results of our experiments with floorless pens on pasture in one way or another.

The floorless pen system used in the present study is designed for small-scale poultry operations. Small groups (60 to 90 birds per pen), controlled stocking rates and effective protection from predators make the system also suitable for experimental research. However, being confined to the surface of the pen at all times, the birds cannot be regarded as free ranging, even though pens moved daily cover more pasture area in total during a broiler's life than most free-range systems offer (floorless pen: 8 to 10 m^2 per bird, Bassler & Ciszuk, 2002; free range: 2.5to 4 m^2 per bird, EC, 1999).

Broilers with access to range would probably have had a larger daily supply and variety of herbage and soil fauna to choose from (Paper I). The systematic cover of the pasture by moving the pens regularly probably decreased disease pressure (Paper II) and influenced the birds' effect on pasture (Paper V). The confinement to the pen probably also limited the birds' physical activity which consequently may have influenced the birds’ leg condition, compared to free range (Papers III & IV).

The floorless pen system can thus offer one desired element in organic broiler husbandry: high control over stocking rate and resting periods for the land to manage bird health and effect on pasture. But it does not or not fully offer another desired element: the contribution of free range to the birds' nutrition and behaviour (Rodenhoff & Dämmrich, 1971, Castellini *et al.*, 2002).

Appleby *et al.* (1992) assume that the floorless pen system, as used for laying hens prior to the 1960s ('fold unit' as mentioned in Robinson, 1953) is extinct. In the US, however, small-scale farmers use the floorless pen system for broiler chickens (APPPA, 2004). One level above the small-scale floorless pen system is the mobile housing system for broilers that are moved after each batch and can hold up to a few thousand birds depending on the design (Gordon & Charles, 2002). The intermediate design is for smaller mobile houses for a few hundred birds that are moved once every 2 to 5 weeks. These houses are usually closed at night but are opened during the day to allow for free range (Beck-Chenoweth, 1996).

Tuberculosis (TB) in humans has been a feared disease in the first half of the 20^{th} century. Compared with the human form of TB (*Mycobacterium tuberculosis*), man is less susceptible to the bovine form of TB and rather resistant to the avian form (*Mycobacterium avium*). But children are much less resistant to the bovine form than adults (Seiden, 1952) and in the 1940s, at least 2000 children in Great Britain died annually after drinking unpasteurized milk infected with bovine TB (*Mycobacterium bovis*) (Bell & Palmer, 1983).

Prevention of TB has been a motivating factor for separating cattle from free-range chickens. Cows only rarely react to exposure to poultry infected with *M. avium* (Seiden, 1952), and in general this does not result in the cow becoming ill or the risk for spreading infection (Rosenberger, 1970).

Chickens younger than two years are much less susceptible to TB than are older birds. In order to minimize the risk of TB in a mixed-grazing system with cattle and chickens, only younger chickens, such as for example broilers and first-year layers, should share pasture with cattle.

The fast-growing genotype ROSS 208 is dominant in all pasture experiments because at the start of the project in 2000, no slow-growing genotype was commercially available in Sweden except for cocks from laying strains like Derco (Anonymous, 1998). It was only in 2001 that the slow-growing ISA 657 was temporarily available and included in the investigations.

The ROSS birds were fed restricted, mainly to maintain an acceptable leg health until the end of the experiment at 12 weeks of age. Zootechnically, the birds performed well (Paper I) and leg condition was good even at 11.5 weeks of age (Paper IV). The generally strong appetite and high-feed intake capacity (Leeson *et al.*, 1996) of fast-growing broilers made restricted-fed ROSS 208 birds a relatively good choice to experimentally test the potential pasture intake of broilers.

However, the birds' behaviour indicated that the applied level of feed restriction led to frustration (Paper III). Since the welfare of these broilers' parents is questionable and remains a critical issue as described in the Introduction, we agree with Thomsen *et al.* (2001) that ROSS 208, as well as probably any other fast-growing genotype, is not suitable for organic production in a long perspective.

Genotypes bred to reach about 2.4 kg body weight at 81 days of age like the ISA 657 are typical of the French market for slow-growing broilers (Label Rouge). This growth rate agrees well with the idea of slow-growing genotypes in organic agriculture. However, in the Label Rouge program, diet supplementation with crystalline amino acids as well as anticoccidial drugs is permitted and practised (Anonymous, 1992), whereas in organic agriculture, the use of crystalline amino acids has so far been regarded as a questionable and temporary measure and, and the use of anticoccidial drugs is generally prohibited.

The outbreak of cannibalism in the restricted-fed ISA 657 groups in our experiment (Paper III) raises the question of the suitability for this genotype to exist on sub-optimal diets. If it would react similarly to a low-protein quality, its value for organic agriculture would be questionable.

Genotypes that can reach 2.2 kg body weight at 56 days such as the ISA 957 (Paper VI) have a growth potential somewhere in between ROSS 208 and ISA 657. If these genotypes are raised under optimal conditions, the daily mean growth rate between day old and 81 days would lie above 35 g per day, which is 5 g above the maximum growth capacity for slow-growing broilers (30 g per day, day 1–81), as mentioned by Pedersen *et al.* (2003) and Hermansen *et al.* (2004). A sub-optimal diet protein quality, as a form of qualitative feed restriction, will reduce this growth rate. The higher growth potential in this genotype compared to the slow-growing genotypes will enhance the effect of compensatory growth (Proudman & Mellen, 1970; Paper VI).

The ideal genotype for organic production is probably a dual-purpose breed of which the hens are used for egg production and the cocks for meat (Postler, 1999; Schiötte, 2001). It can be seen as ethically rather precarious to sacrifice all male birds from egg-laying strains when one day old (BMVEL, 2003). In the European Union, this practice would amount to about 280 million day-old chicks per year (FAL, 2001). The (re-)introduction of dual-purpose chicken breeds to agriculture would imply a reduced level of growth performance compared with today's conventional production, because the net effects of genetic increases in growth rate on egg production are negative (Chambers, 1993).

The limiting factor in feeding 100% organic and preferably on-farm diets in northwestern Europe appears to be protein quality, and particularly the essential amino acid methionine (Elwinger, 1996). Methionine has a wide variety of functions in the animal and plays an important role for the growth of muscles and feathers. Most vegetable feedstuffs have relatively low methionine contents, compared with the nutritional recommendations for broilers (Thomke, 1983). Processed potato protein and corn gluten have considerably higher methionine contents but can usually not be produced on-farm.

Protein from meat and bone meal and milk contains higher levels of methionine s than most vegetable protein, and the protein quality of fish and eggs in this respect is outstanding. The use of fish meal has become an environmental issue since the world's marine fish catch is facing diminishing returns due to resource depletion (Harrison & Pearce, 2000). Milk and eggs are high-quality animal products and their use as feedstuffs should, from an ecological perspective, be limited to products that cannot be used otherwise such as dirty or broken eggs, colostrum or whey (Ciszuk, 2005). Meat and bone meal appear to fit well with the organic principle of nutrient recycling but has been prohibited for use in poultry feeds within the EU since the outbreak of bovine spongiform encephalopathy (BSE) (EC, 2001). Whether or not crystalline amino acids should be accepted generally in organic broiler and egg production or rather seen as temporal exception from organic production standards has been an issue of discussion (Elwinger, 2005). The production of amino acids is environmentally not friendly (OMRI, 1999) but insufficient protein quality in poultry feed is reducing production performance, is possibly affecting animal health negatively, and leads to an increased N content of the excreta, requiring effective methods of recycling this nutrient in the agro-ecosystem.

If the broilers shall be given access to range at three to four weeks of age, it may be advisable to feed the birds fully to their nutritional recommendations up to that age. At the end of the starter period the birds then have the maximum body size for that age which may positively affect ranging ability and reaction to predators. Further, the absolute size of the digestive tract will support the bird to cope with

feed found on the range. If the diet after three to four weeks of age should have a sub-optimal protein quality, these birds would be more able to cope with that, than birds that had been fed restricted at a lower age (Harper *et al.*, 1970).
If the main protein and the main energy source are offered separately in a choice feeding system, the birds might be able to partly compensate a sub-optimal protein quality through diet selection and compensatory growth. The results presented in Paper VI support this idea. Since the bird's weekly intake of feed is relatively low during the first three weeks when compared with weeks 4 to 12, extra investments in the starter diet may be economically viable.

Free-choice feeding (Emmans, 1991) can be an economically advantageous feeding system, especially when on-farm feedstuffs are included in the diet (Tauson *et al.*, 1991, Ciszuk & Charpentier, 1996). The requirement for access to free range with its changing weather conditions and likely individual differences in the birds' physical activity make this feeding system interesting particularly for organic farming. A commonly used choice-feeding system offers a choice between a protein concentrate and whole grain. The majority of publications that report experiments with choice feeding support the view that chickens are able to compose an optimal diet from an appropriate set of feedstuffs. However, not all experiments were successful (Hughes, 1984) and the issue has been a matter of scientific dispute (Cumming & Mastika, 1987).

It is well established that the diet's energy concentration is a major factor in determining a bird's total-feed intake (Scott *et al.*, 1976). It has been shown that broilers in choice-feeding systems react to diets deficient in certain amino acids by composing their diets in a direction that better meets their nutritional requirements, although with varying results (Newman & Sands, 1983; Steinruck *et al.*, 1990; Steinruck & Kirchgessner, 1992). It has further been shown that broilers in choice-feeding systems with a protein concentrate and whole grain steadily increased the intake of whole grain with increasing age, well in accordance with their decreasing protein demands (Cowan & Michie, 1978; Scholtyssek, 1982: Leeson & Caston, 1993). In contrast to this, chickens over-consumed protein in other experiments (Kiiskinen, 1987; Farrell *et al.*, 1989;), suggesting a less effective regulatory mechanism in the birds (Newman & Sands, 1983), a lack of training (Forbes & Shariatmadari, 1994) or an effect of taste (Hughes, 1984).

In the experiment presented in Paper VI, free-choice feeding was applied in order to measure both the feed consumption and the feed choice of the broilers. The aim of the experiment was not only to measure the birds' performance when fed a diet low in methionine, but also in which way the birds would react when offered the free-choice diet and, under these conditions, to what extent the birds compensate for the low methionine content of the feed.

Protein over-consumption is undesirable both for economic and environmental reasons. A semi-choice feeding system that offers a limited amount of protein feed next to *ad libitum*-fed cereals would still have the advantage to let the individual animal adapt its energy intake to varying requirements, for example due to changing weather conditions.

Conclusions

The summarized results presented here support the view that there is a promising potential to rear broiler chickens organically. It is likely that imbalances (imbalances according to the concept of organic agriculture) in the broilers (e.g. disorders or diseases) or imbalances in the agro-ecosystem (e.g. lack or excessive surplus of nutrients) can thereby be avoided. The development of organic broiler production would thus support efforts to adopt more sustainable ways of agriculture.
These conclusions can be drawn from the investigated perspectives of animal nutrition, agro-ecology, behaviour and health, with the available bird genotypes, and for North Western Europe. The current work did not investigate socio-economic issues like for example profitability, consumer preferences or working conditions.

The results from the present experiments led to the particular conclusions that:

Pasture does not offer sufficient energy and protein to allow feed savings in a broiler farm enterprise, under the conditions of the presented experiments.

Daily moved pens provide favourable conditions for preventing infections with coccidiosis in outdoor broilers. No C*ampylobacter* was found in the birds on pasture.

The hypothesis that pasture is a stimulus for physical activity in broilers and consequently affects leg condition could not be verified. The confinement of the birds to the area of the pen is a possible explanation for this result.

Broiler chickens on pasture can sustain white clover in a mixed grass/white clover pasture and thus benefit mixed-grazing systems.

There seems to be a potential to produce broiler meat in North Western Europe with feed produced on-farm, even though the feeds' methionine concentration is below today's conventional standards.

Suggested further research:

- Investigation of alternatives to chicken meat production in northwestern Europe, from an agro-ecosystems perspective, e.g. fish, ducks, geese, rabbits, nutria (*Myocastor coypus*).

- Investigation of long-term effects of pastured chickens on grass/clover swards (herbage yield and botanical composition).

- Identification of a sustainable scale of broiler production in an agro-ecosystem, from an organic perspective.

- Breeding a dual purpose chicken for meat and egg production.

- Development of on-farm diets (screening of feedstuffs, testing of diets).

- Investigating the potential to cultivate worms and insects as chicken feed, preferably on-farm or in the region.

- Investigating the nutritional contribution of different types of pasture in combination with different bird x housing systems.

- Investigating the nutritional contribution of pasture in form of minerals and vitamins.

- Definition of resting periods for the land as a mean of disease prevention for different housing systems.

- Development of winter housing systems.

References

Alrøe, H.F. & Kristensen, E.F. 2002. Science as an actor. On the role of values and science in organic farming. Paper presented at UK Organic Research 2002, Aberystwyth, 26-28 March, 2002. Organic Centre Wales. 97-100.

Anonymous. 1992. General direction of feeding. Ministere de l'agriculture et du developpement rural. Notice technique, Paris. pp. 17. (In French)

Anonymous. 1998. Derco. Krutmöllans Hönsgård, Kävlinge, Sweden. (In Swedish).

Anonymous 2004. 20 years of production enhancement. Broilers. World Poultry 20 (10), 42-43.

Appleby, M.C., Hughes, B.O. & Elson, A. 1992. Poultry Production Systems. CABI Publishing, Wallingford.

APPPA 2004. American Pastured Poultry Producer's Association. Hartselle AL. http://apppa.org/.

Aviagen 2004. ROSS Broiler Management Manual. Midlothian, Scotland.www.aviagen.com.

Bassler, A., Ciszuk, P. & Sjelin, K. 2000. Management of laying hens in mobile houses - A review of experiences. In: Hermansen, J.E., Lund, V. & Thuen, E., (Eds.) Ecological animal husbandry in the Nordic countries. Proceedings from NJF-seminar No. 303, Horsens, Denmark, 16-17 September 1999. Danish Research Centre for Organic Agriculture (DARCOF), Tjele, Denmark. 45-50.

Bassler, A. & Ciszuk, P. 2002. Pilot studies in organic broiler production. Ekologiskt lantbruk Nr. 34. Centre for Sustainable Agriculture, Swedish University of Agricultural Sciences, Uppsala.

Beck-Chenoweth, H. 1996. Free-Range Poultry Production and Marketing. Back Forty Books, Creola, OH.

Bell, J.C. & Palmer, S.R. 1983. Control of Zoonosis in Britain: past, present and future. British Medical Journal (287) 591-593.

Berg, C. 1998. Foot-pad dermatitis in broilers and turkeys - prevalence, risk factors and prevention. PhD-Thesis, Swedish University of Agricultural Sciences, Dept. of Animal Environment and Health. Skara.

Berg, C. 2001. Health and welfare in organic poultry production. Acta Veterinaria Scandinavica 95, 37-45.

Bertalanffy, L.v. 1968. General Systems Theory. Penguin Press, London. pp. 315.

Bird, A. 2005. "Thomas Kuhn" In: Zalta, E.N. (Ed.) The Stanford Encyclopedia of Philosophy (Spring 2005 Edition). http://plato.stanford.edu/archives/win2003/entries/thomas-kuhn/

Björklund, J., Limburg, K.E. & Rydberg, T. 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. Ecological Economics 29, 269-291.

BMVEL 2003. Tierschutzbericht 2003. Bericht ueber den Stand der Entwicklung des Tierschutzes. Bundesministerium fuer Verbraucherschutz, Ernährung und Landwirtschaft, Bonn.

Butterworth, A. 2004. Infectious diseases: Morbidity and Mortality. In: Weeks, C.A. & Butterworth, A. (Eds.) Measuring and auditing broiler welfare. CABI Publishing, Wallingford. 61-70.

Caffrey, J.P. 1994. Status of bovine tuberculosis eradication programmes in Europe. Veterinary Microbiology 40, 1-4.

Castellini, C., Mugnai, C. & Dal Bosco, A. 2002. Effect of organic production system on broiler carcass and meat quality. Meat Science 60, 219-225.

Cederberg, C. 2002. Life cycle assessment (LCA) of animal production. PhD-Thesis. Dept. of Applied Environmental Science. Gothenborg University. Sweden.

Chambers, J.R. 1993. Genetics of growth and meat production in chickens. In: Crawford, R.D. (Ed.) Poultry Breeding and Genetics, 599-644. Elsevier, Amsterdam.

Cheema, M.A., Qureshi, M.A. & Havenstein, G.B. 2003. A comparison of the immune response of a 2001 commercial broiler with a 1957 randombred broiler strain when fed representative 1957 and 2001broiler diets. Poultry Science 82. 1519-1529.
Ciszuk, P. & Charpentier, L. 1996. Fritt foderval för värphöns. Ekologisk lantbruk 20. The Swedish University of Agricultural Sciences, Uppsala. 127-134.
Ciszuk, P., 1999. Diagrammic illustration of a mixed farming system with cattle and pastured chickens, scetching potential links between animal species and on-farm feed. Unpublished. Swedish University of Agricultural Sciences. Dept. of Animal Nutrition and Management. Uppsala.
Ciszuk, P. 2004. Personal communication. Swedish University of Agricultural Sciences. Dept. of Animal Nutrition and Management. Uppsala.
Conway, G. 1985. Agroecosystem analysis. Agricultural Administration 20. 31-55.
Coppock, D.L. 1993. The Borana Plateau of Southern Ethiopia: Synthesis of pastoral research, development and change, 1980-91. ILCA Systems Study. International Livestock Centre for Africa, Addis Abeba.
Cottingham, J., Stoothoff, R. & Murdoch, D. 1984. The Philosophical Writings of Descartes. Cambridge University Press, Cambridge.
Coulsen, R.N. 1992. Intelligent geographic information systems and integrated pest management. Crop Protection 11(6), 507-516.
Cowan, P.J. & Michie, W. 1978. Choice feeding of the male and female broiler. British Poultry Science 19, 149-152.
Cumming, R.B. & Mastika, I.M. 1987. Why choice feeding trials have failed. Proceedings of the poultry husbandry research foundation symposium, University of Sydney. 23-29.
Decuypere, E. & Verstegen, M. 1999. Stoffwisselingsinzichten en voeding bij pluimvee. Tijdschrift voor diergeneeskunde 124(2), 47-51.
DeHaan, C., Steinfeld, H. & Blackburn, H. 1997. Livestock & the environment: finding a balance. Directorate General for Development, Commission of the European Community, Brussels, Belgium.
EC 1999. Council Regulation (EC) No 1804/1999 of 19 July 1999 supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs to include livestock production. Official Journal of the European Communities 24.98.1999, Brussels. L 222 1-28.
EC 2001. Commission decision of 27 December 2000 prohibiting the use of certain animal by-products in animal feed. Official Journal of the European Communities. C(2000) 4143, Brussels. L6 16-17.
EC 2004.Communication from the commission to the council and the European parliament: European action plan for organic food and farming. SEC(2004)739. Commission of the European Community. Brussels. pp. 7.
Elwinger, K. 1996. Proteinförsörjningen är problemet. Forskningsnytt om ökologisk landbruk i Norden 5, The Swedish University of Agricultural Sciences, Uppsala. 4-6. (In Swedish)
Elwinger K. 2005. Personal communication. Swedish University of Agricultural Sciences. Dept. of Animal Nutrition and Management. Uppsala.
Emmans, G. C. 1991. Diet selection by animals: theory and experimental design. Proceedings of the Nutrition Society 50, 59-64.
FAL. 2001. Jahresbericht 2001. Bericht des Instituts fuer Tierzucht und Tierverhalten. Bundesforschungsanstalt fuer Landwirtschaft, Braunschweig.
Farrell, D.J., Ball, W., Thompson, E., Abdelsamie, R.E. & Pesti, G.M. 1989. How well do layers discriminate given choices of grain and protein concentrate? Recent Advances in Animal Nutrition in Australia. 311-321.
Forbes, J.M. & Shariatmadari, F. 1994. Diet selection for protein by poultry. World's Poultry Science Journal 50, 7-24.
Frid, G. 1999. Nytt ramprogram för forskning inom ekologisk produktion. Djuridiken 4, Jönköping, Statens Jordbruksverk (The Swedish Board of Agriculture).p. 9. (In Swedish).
Gibon, A., Sibbald, A.R. & Thomas, C. 1999. Improved sustainability in livestock systems, a challenge for animal production science. Livestock production Science 61, 107-110.

Gordon, S.H. & Charles, D.R. 2002. Niche and Organic Chicken Products. Nottingham University Press.

Guyton, A.C. & Hall, J.E. 1996. Textbook of Medical Physiology. W.B. Saunders Company, Philadelphia.

Harper, A.E., Benevenga, N.J. & Wohlhueter, R.M. 1970. Effects of ingestion of disproportionate amounts of amino acids. Physiological Reviews 50(3), 428-558.

Harrison, P. & Pearce, F. 2000. AAAS Atlas of Population and Environment. American Association for the Advancement of Science, Washington, D.C.

Havenstein, G.B., Ferket, P.R., Scheideler, S.E. & Larson, B.T. 1994. Growth, livability, and feed conversion of 1957 vs. 1991 broilers when fed "typical" 1957 and 1991 broiler diets. Poultry Science 73, 1785-1794.

Hermansen, J.E., Strudsholm, K. & Horsted, K. 2004. Integration of organic animal production into land use with special reference to swine and poultry. Livestock Production Science 90, 11-26.

Heuer, O.E., Pedersen, K., Andersen, J.S. & Madsen, M. 2001. Prevalence and antimicrobial susceptibility of thermophilic Campylobacter in organic and conventional broiler flocks. Letters in Applied Microbiology 33, 269-274.

Hill, S.B. 1982. Steps to a holistic ecological food system. 15-21. Birkhäuser Verlag. 2nd International Conference, International Federation of Organic AgricultureMovements (IFOAM). 10-1-9780.

Hocking, P.M. & Maxwell, M.H. 1993. Welfare aspects of different degrees of food restriction during rearing of broiler parent females. In: Savory, C.J. and Hughes, B.O.(Eds.) Proceedings of the Fourth Symposium on Poultry Welfare. Edinburgh, Sept. 18th-21st 1993, Universities Federation for Animal Welfare. For: Working Group IX of the European Federation of the World's Poultry Science Association. 254-256.

Hocking, P.M., Bernard, R. & Robertson, G.W. 2002. Effects of low dietary protein and different allocations of food during rearing and restricted feeding after peak rate of lay on egg production, fertility and hatchability in female broiler breeders. British Poultry Science 43, 94-103.

Hocking, P. M. 2004. Measuring and auditing the welfare of broiler breeders. In: Weeks, C. A. & Butterworth, A. (Eds.) Measuring and auditing broiler welfare, CABI Publishing, Wallingford. 19-35.

Hodgson, J. 1979. Nomenclature and definitions in grazing studies. Grass and Forage Science 34, 11-18.

Hughes, B.O. 1984. The principles underlying choice feeding - with special reference to production experiments. World's Poultry Science Journal 40(2), 141-150.

IFOAM 2002. IFOAM Basic Standards for Organic Production and Processing. International Federation of Organic Agriculture Movements (IFOAM). Bonn.

Julian, R.J. 2004. Evaluating the impact of metabolic disorders on the welfare of broilers. In: Weeks, C.A. & Butterworth, A. (Eds.) Measuring and auditing broiler welfare, 51-59. CABI Publishing, Wallingford.

Kestin, S.C., Knowles, A.E., Tinch, A.E. & Gregory, N.G. 1992. Prevalence of leg weakness in broiler chickens and its relationship with genotype. Veterinary Record 131, 190-194.

Kestin, S.C., Gordon, S., Su, G. & Sorensen, P. 2001. Relationships in broiler chickens between lameness, liveweight, growth rate and age. Veterinary Record 148, 195-197.

Koenen, M.E., Boonstra-Blom, A.G., Jeurissen, S.H.M. 2002. Immunological differences between layer- and broiler-type chickens. Veterinary Immunology and Immunopathology 89. 47-56.

Koenig, C. 2002. Vitalitätsforschung. Forschungsinstitut für Vitalqualität.Wetzikon, CH. www.fiv.ch. (In German).

Kuhn, T. S. 1970. The structure of scientific revolutions. The University of Chicago Press, Chicago.

Lamont, S.J., Pinard-van der Laan, M.H., Cahaner, A., Van der Poel, J.J. & Parmentier, H.K. 2003. Selection for disease resistance: direct selection on the immune response. In: Muir, W.M. & Aggrey, S.E. (Eds.) Poultry genetics, breeding and biotechnology, CABI Publishing, Wallingford. 399-418.

Lampkin, N. 1990. Organic Farming. Farming Press Books, Ipswich.
Lantinga, E.A., Oomen, G.J.M. & Schiere, J.B. 2004. Nitrogen efficiency in mixed farming systems. Journal of Crop Improvement 12(1/2), 437-455.
Leeson, S. & Caston, L.J. 1993. Production and carcass yield of broilers using free-choice cereal feeding. Journal of Applied Poultry Research 2, 253-258.
Leeson, S., Caston, L.J. & Summers, J.D. 1996. Broiler response to energy or energy and protein dilution in the finisher diet. Poultry Science 75, 522-528.
Lund, V. & Röcklinsberg, H. 2001. Outlining a conception of animal welfare for organic farming systems. Journal of Agricultural and Environmental Ethics 14, 391-424.
McNaughton, S.J. 1976. Serengeti migratory wildebeest: facilitation of energy flow by grazing. Science 191(4222), 92-94.
McRae, R.J., Hill,S.B., Henning, J.,& Mehuys, G.R. 1989. Agricultural Science and sustainable agriculture: a review of the existing scientific barriers to sustainable food production and potential solutions. Biological Agriculture & Horticulture 6, 173-219.
Merrill, M.C. 1983. Eco-Agriculture: A Review of its History and Philosophy. Biological Agriculture and Horticulture 1, 181-210.
Morton, D.B. 2004. Does broiler welfare matter, and to whom? In: Weeks, C. A. & Butterworth, A. (Eds.) Measuring and auditing broiler welfare, CABI Publishing, Wallingford. 241-250.
Newman, R.K. & Sands, D.C. 1983. Dietary selection for lysine by the chick. Physiology and Behaviour 31, 13-19.
Newton, I. 1686. Sir Isaac Newton's Mathematical Principles of Natural Philosophy and His System of the World. Kessinger Publishing, Whitefish, MT. 720 pp.
Nolan, T. & Connolly, J. 1977. Mixed stocking by sheep and steers - a review. Herbage abstracts 47(11), 367-374.
Nolan, T. 1992. Systems of mixed grazing research and extension - A case history. Proceedings of the II. Intl. Symposium on Livestock Farming Systems. EAAP publication No.63.
Oden, K. 1994. Höns och andra fjäderfän. LTs förlag, Stockholm. (In Swedish).
OMRI. 1999. Amino acids, livestock. US Ntl. Organic Standards Board (NOSB) Materials Database. Organic Materials Review Institute (OMRI), Eugene, OR.
Oomen, G.J.M., Lantinga, E.A., Goewie, E.A. & Van der Hoek, K.W. 1998. Mixed farming systems as a way towards a more efficient use of nitrogen in Eurpean Union agriculture. Environmental Pollution 102(S1), 697-704.
Pedersen, M.A., Thamsborg, S.M., Fisker, C., Ranvig, H. & Christensen, J.P. 2003. New production systems: evaluation of organic broiler production in Denmark. Journal of Applied Poultry Research 12, 493-508.
Perez, A.M., Weimar, M.R. & Cromer, S. 1991. U.S. Egg and poultry statistical series 1960-90. Station Bulletin 833. USDA, Economic Research Service. p. 110.
Postler & G. 1999. Europas Weg zur Biohenne. Ökologie & Landbau 27(4), p. 26. (In German)
Proudman, J.A. & Mellen, W.J. 1970. Utilisation of feed in fast- and slow-growing lines of chickens. Poultry Science 49, 961-972.
Rauw, W.M., Kanis, E., Noordhuizen-Stassen, E.N. & Grommers, F.J. 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livestock Production Science 56, 15-33.
Robinson, L. 1953. Modern Poultry Husbandry. Crosby Lockwood, London.
Rodenburg, T.B. & Van Harn, J. 2004. Biologische vleeskuikenhouderij. Praktijkrapport Pluimvee 11. Animal Sciences Group, Praktijkonderzoek. Lelystad.
Rodenhoff, G. & Dämmrich, K. 1971. Ueber die Beeinflussung des Skeletts der Masthähnchen durch Haltung und Auslauf im Freien. Zentralblatt fuer Veterinärmedizin, A 18, 297-309. (In German).
Rosenberger, G. 1970. Krankheiten des Rindes. Paul Parey, Berlin. (In German).
Sands, D.M. 1986. Farming systems research: clarification of terms and concepts. Experimental Agriculture 22, 87-104

Sanotra, G.S. & Berg, C. 2003. Investigation of Lameness in the Commercial Production of Broiler Chickens in Sweden. Specialarbete 22. Swedish University of Agricultural Sciences, Dept. of Animal Environment and Health. Skara.

Savory, C.J., Wood-Gush, D.G.M. & Duncan, I.J. 1978. Feeding behaviour in a population of domestic fowls in the wild. Applied Animal Ethology 4, 13-27.

Savory, C.J. & Maros, K. 1993. Influence of degree of food restriction, age and time of day on behaviour of broiler breeder chickens. Behavioural Processes 29, 179-190.

Savory, C.J., Maros, K. & Rutter, S.M. 1993. Assessment of hunger in growing broiler breeders in relation to a commercial restricted feeding programme. Animal Welfare 2, 131-152.

Savory, C.J. 1995. Broiler welfare: problems and prospects. Archiv fur Geflügelkunde Sonderheft 82, 48-52.

SCAHAW 2000. The welfare of chickens kept for meat production (broilers). Report of the Scientific Committee on Animal Health and Welfare. European Commission Report B3, R 15, 2000. Health & Consumer Protection Directorate-General. Brussels.

Scheele, C.W. 1997. Pathological changes in metabolism of poultry related to increasing production levels. The Veterinary Quarterly 19(3), 127-130.

Schiere, J.B. & Rickert, K. 2004. Technology and development: a gravy train? In: Rickert, K. (Ed.) Emerging challenges for farming systems - lessons from Australian and Dutch agriculture. Kingston Act 2604. 87-105.

Schiere, J.B., Groenland, R., Vlug, A. & VanKeulen, H. 2004. System thinking in agriculture: an overview. In: Rickert, K. (Ed.) Emerging challenges for farming systems - lessons from Australian and Dutch agriculture. Kingston Act 2604. 57-86.

Schiötte, F. 2001. Hönsskötsel på rimligt vis. Boskogen, Göteborg. (In Swedish)

Scholtyssek, S. 1982. Beitrag zur Wahlfuetterung von Broilern. Archiv fuer Geflügelkunde 46, 243-247. (In German)

Scott, M.L., Nesheim, M.C. & Young, R.J. 1976. Nutrition of the chicken. M.L. Scott & Associates, Ithaca NY.

Sehestedt, J., Monrad, J., Söegaard, K. & Danielsen, V. 2000. Performance and parasitosis in heifers grazing mixed with sows. 51st Annual Meeting of the EAAP, Aug. 2000. Abstract No.373. European Association for Animal Production. The Hague, NL. 21-24.

Seiden, C.E. (ed.) 1952. Livestock Health Encyclopedia, Springer Verlag, NewYork.

Smith, D.W. 2003. Phenomenology. In: Zalta, E.N. (Ed.) The Stanford Encyclopedia of Philosophy (Winter 2003 edition). http://plato.stanford.edu/archives/win2003/entries/phenomenology/

Statistics Sweden 2004. Yearbook of Agricultural Statistics 2004. Stockholm.

Steiner, R. 1924. Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft. Landwirtschaftlicher Kursus. Rudolf Steiner Verlag, Dornach, Switzerland. (In German).

Steinruck, U., Roth, F.X. & Kirchgessner, M. 1990. Selektive Futteraufnahme von Broilern bei Methioninmangel (Selective feed intake of broilers during methionine deficiency). Archiv fuer Geflügelkunde 54(5), 173-183. (In German).

Steinruck, U. & Kirchgessner, M. 1992. Einfluss von nutritiven Faktoren während einer Lernphase auf die Entstehung eines spezifischen Lysinhungers bei Legehennen. Journal of Animal Physiology and Animal Nutrition 68, 43-52. (In German).

Strid Eriksson, I. 2004. Environmental Systems Analysis of Pig Production. PhD-thesis. Swedish University of Agricultural Sciences, Department of Biometry and Engineering.

Tarver, F.R. Jr. 1986. Poultry and egg marketing. National Food Review 1986. Economic Research Service. USDA, Washington D.C. 20-22.

Tauson, R., Jansson, L. & Elwinger, K. 1991. Whole grain/crushed peas and a concentrate in mechanised choice feeding for caged laying hens. Acta Agriculturae Scandinavica 41, 75-83.

Thaer, K. 1990. Free range poultry. Farming Press. Ipswich, UK:

Thomke, S. 1983. Det hemproducerade foderproteinets kvalitet - behov av komplettering till icke-idisslare (The quality of domestically produced feed protein - requirements of supplementation to non-ruminants). Skogs- och Lantbruksakademiens Tidskrift. (Suppl.15: Fodderprotein from Swedish plant husbandry - The role of plant nutrients - Present situation), 14-22.

Thomsen, M.G., Nielsen, B.L., Young, J.F. & Sørensen, P. 2001. Opdræt af frilandskyllinger. Grøn Viden, Husdyrbrug nr.23. Danmarks Jordbrugsforskning. Forskningscenter Foulum, Tjele. 2-8.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S. 2002. Agricultural sustainability and intensive production processes. Nature 418(8), 671-677.

UNCED.1992. Agenda 21. The Rio Declaration on Environment and Development, and the Statement of Principles for the Sustainable Management of Forests. 3-14 June, 1992, Rio de Janeiro, Brazil. United Nations Conference on Environment and Development (UNCED).

Van Harn, J. & Van Middelkoop, K. 2001. Is there a future for slow growing broilers? World Poultry 17(8), 26-27.

Verstegen, M. & Jongbloed, A.W. 2003. Christalline amino acids and nitrogen emission. In: D'Mello, J.P.F. (Ed) Amino acids in animal nutrition. CABI Publishing, Cambridge. 449-458.

Waldenstedt, L. 1998. Coccidial and clostridial infections in broiler chickens - influence of diet composition. PhD-Thesis. Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management. Uppsala.

Walker, A. 2001. Reducing the costs of broiler production. ADAS/IGER/University of Bristol. ADAS factsheets, No. 523.

WCED 1987. Our common future. World Commission on Environment and Development (WCED). United Nations Environment Programme. Oxford University Press, Oxford. pp. 372.

Weaver, T. 1998. Giving broilers a firmer leg to stand on. Agricultural Research (May 1998) USDA. p. 6.

Wegner, R.M. 1982. Untersuchungen über Haltungsmethoden von Legehennen unter Berücksichtigung ethologischer Aspekte. Landbauforschung Völkenrode 32(3), 162-166. (In German).

Whitehead, C.C., Fleming, R.H. & Julian, R.J. 2003. Skeletal problems associated with selection for increased production. In: Muir, W.M. & Aggrey, S.E. (Eds.) Poultry genetics, breeding and biotechnology. CABI Publishing. 29-52.

Yu, M.W., Robinson, F.E. & Roblee, A.R. 1992. Effect of feed allowance during rearing and breeding on female broiler breeders. 1. Growth and carcass caracteristics. Poultry Science 71, 1739-1749.

Yunis, R., Ben-David, A., Heller, E.D. & Cahaner, A. 2000. Immunocompetence and viability under commercial conditions of broiler groups differing in growth rate and in antibody response to Escherichia coli vaccine. Poultry Science 79, 810-816.