ENVIRONMENT, WELL-BEING, AND BEHAVIOR

Effects of different broiler production systems on health care costs in the Netherlands

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ABSTRACT This study analyzed the effects of different broiler production systems on health care costs in the Netherlands. In addition to the conventional production system, the analysis also included 5 alternative animal welfare systems representative of the Netherlands. The study was limited to the most prevalent and economically relevant endemic diseases in the broiler farms. Health care costs consisted of losses and expenditures. The study investigated whether higher animal welfare standards increased health care costs, in both absolute and relative terms, and also examined which cost components (losses or expenditures) were affected and, if so, to what extent. The results show that health care costs represent only a small proportion of total production costs in each production system. Losses account for the major part of health care costs, which makes it difficult to detect the actual effect of diseases on total health care costs. We conclude that, although differences in health care costs exist across production systems, health care costs only make a minor contribution to the total production costs relative to other costs, such as feed costs and purchase of 1-d-old chicks.

Key words: animal welfare, animal health, economic analysis, broiler production

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INTRODUCTION

In recent years, increasing requirements regarding animal welfare (**AW**) in broiler production have led to the development of production systems that comply with above-legal AW standards (Blokhuis et al., 2003; Fraser, 2006). Although these standards contribute to improved AW, they also increase production costs (Verspecht et al., 2011). Furthermore, productivity and profitability might be negatively affected if higher production costs do not increase economic returns (McInerney, 2004).

Although livestock diseases occur in broiler farms regardless of which production system is used, the likelihood and the effect of livestock diseases can differ depending on the production system. However, the possible effect of AW-friendly production systems on animal health is not clear. Lister and Van Nijhuis (2012) suggested that the prevalence of coccidiosis or other parasitic infections was higher in systems in which chickens had access to an outdoor area, such as free-range or organic systems. Also, broiler chickens in organic systems showed an increased prevalence of *Campylobacter* compared with chickens in conventional systems. Cui et al. (2005) found that organic chickens were more frequently contaminated with *Campylobacter* and *Salmonella*. In contrast, Van Overbeke et al. (2006) found no significant difference in the prevalence of *Salmonella* between broiler chickens kept in organic and those kept in conventional systems.

With respect to the possible effect of AW-friendly production systems on animal health, a distinction must be made between prevalence (that is, the likelihood of introduction) and effect. Increased disease prevalence and a greater effect of a disease both result in increased health care costs. Health care costs include all economic effects of a disease and are the sum of 2 components: losses and expenditures (McInerney, 1996). Losses can be caused, for example, by mortality, morbidity, reduced production efficiency, and lower meat yield and quality, which results in reduced returns. Extra expenditures are mainly the costs of veterinary prophylactic and therapeutic treatments to prevent or treat a disease (McInerney et al., 1992; Bennett, 2003; Houe, 2003; Bennett and Ijpelaar, 2005).

The aim of this study was to analyze the effects of different production systems on health care costs. First, we investigated whether higher AW standards increased health care costs in both absolute and relative terms. Second, we examined which cost components (losses or expenditures) were affected and to what extent. This study was restricted to the most important endemic diseases. Epidemic diseases, such as avian influenza,

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Table 1. Requirements and criteria of selected animal welfare concepts (Ellen et al., 2012)

	Production system					
Criteria	Conventional	Volwaard	Better Life 1*/ Puur & Eerlijk	Better Life 2*	Better Life 3*/ Skal	Organic
Breed	Fast-growing	Slower-growing	Slower-growing	Slower-growing	Slow-growing	Slow-growing
Length of growth period (d)	40	56	56	56	81	70
Enrichment	Litter	Litter Grains and straw	Litter Grains and straw	Litter Grains and straw	Litter	Litter
Stocking density (chicken/m^2)	No restriction	No restriction	12	13	7	10
Stocking density (kg/m^2)	42	31	25	27.5	No restriction	No restriction
Outdoor access	No	Covered veranda	Covered veranda	Yes (1 m^2/ chicken)	Yes (1.5 m^2/ chicken)	Yes (4 m^2/ chicken)
Lighting regimen	Unnatural (minimum 4 h dark period)	Natural (minimum 6 h dark period)	Natural (minimum 6 h dark period)	Natural (minimum 8 h dark period)	Natural (minimum 8 h dark period)	Natural (minimum 8 h dark period)
Flock size	No restriction	No restriction	No restriction	No restriction	No restriction	Maximum 4,800 chickens per barn
Use of antibiotics	No restriction	No restriction	No restriction	No restriction	Coccidiostat and preventive drugs are prohibited	Coccidiostat and preventive drugs are prohibited

were not included because they occur only rarely and the differentiation between conventional, free-range, and organic was less relevant.

MATERIALS AND METHODS

Broiler Production in the Netherlands

Dutch legislation defining standards of broiler production is based on the European Union guidelines (EC, 2007a,b, 2008). In the Netherlands, several so-called AW concepts, such as private labels, have been developed in recent years setting higher requirements for production in terms of AW compared with the minimum standards of conventional broiler production. Table 1 describes the main requirements for conventional production and 5 alternative AW concepts (also referred to as AW systems later in the text) representative for the Netherlands.

A conventional system is defined according to European Union standards. The Better Life hallmark initiated by the Dutch Society for the Protection of Animals (Dierenbescherming) enables a transparent differentiation among animal products in terms of AW. Products that can be produced under different concepts are labeled with a distinctive Better Life logo if they comply with the requirements of this hallmark. Three categories are distinguished within the Better Life hallmark depending on the level of AW: Better Life 1*, Better Life 2*, and Better Life 3*. The number of stars increases as the assumed level of welfare increases. Puur & Eerlijk products fit under the Better Life 1* concept. This concept has the same requirements as in the Volwaard concept, except that a lower stocking density is required (25 kg per m^2). The requirements of Better Life 3* concept are the same as the production standards of SKAL (the independent organization that audits organic systems in the Netherlands). The organic standards of SKAL are different from the European Union standards for organic production, but the European Union standards should eventually be implemented in all European Union countries, which means that the European Union standards for organic production are included in the study as well.

Endemic Diseases Included in the Study

The study was limited to the most important endemic diseases because it was not possible to include all poultry diseases that can occur on a broiler farm. The selection of diseases was mainly based on Bergevoet et al. (2010), who identified the most important diseases and disorders in a broiler farm in the Netherlands by scoring them on several aspects, such as epidemiology and business economics. In this way, infectious bronchitis (**IB**), coccidiosis, *Escherichia coli*, and necrotic enteritis (**NE**) were included in this study, along with infectious bursal disease (**IBD**), sudden death syndrome (**SDS**), ascites, and leg problems (European Commission, 2000; De Jong et al., 2012). *Enterococcus*, which had a relatively high score in terms of epidemiological and business economics aspects, had to be excluded because little is known about its spread and pathogens (Bergevoet et al., 2010). Diseases for which vaccinations are obligatory in the Netherlands, such as Newcastle disease, were excluded from the study (GD, 2012). The selected diseases were considered to be the most prevalent diseases in the broiler farms; they were economically relevant and could be distinguished between systems (Ruff, 1999; European Commission, 2000; Bennett and Ijpelaar, 2005; Rushton, 2009; Bergevoet et al., 2010; De Jong et al., 2012). Because the prevalence and severity of diseases of a particular organ system can differ depending on housing conditions, the 8 selected diseases were categorized into 5 groups according to organ system: diseases concerning the respiratory system (IB), the organs of immune system (IBD), the gastrointestinal tract (coccidiosis, *E. coli*, and NE), the locomotion system (leg problems), and the heart and vascular system (ascites and SDS; Table 2). The final selection was discussed with an expert from the Dutch Animal Health Service who specializes in poultry diseases (J. J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication).

Definition of Health Care Costs

McInerney et al. (1992) defined health care costs ($\boldsymbol{C}$) as the sum of losses ($\boldsymbol{L}$) and expenditures ($\boldsymbol{E}$). A loss implies a foregone benefit, such as lower revenue or lower productivity as a consequence of slower growth (McInerney et al., 1992; McInerney, 1996). Expenditures mainly originate from disease prevention and treatments (McInerney et al., 1992). Evidently, a trade-off exists between L and E: higher treatment and prevention expenditures result in lower losses, and vice versa; the optimal level of L and E is determined by the prices of inputs and outputs (McInerney, 1996). It is possible that a lower output caused by a disease coincides with a lower input such as feed consumption. In this case, the loss can be calculated in such a way that the input saved is deducted from the loss incurred (McInerney et al., 1992).

Calculation Approach

To enable calculation of absolute and relative production costs, a baseline situation must first be defined: no endemic disease present on the farm. System requirements, such as breed, enrichment, stocking density, and input variables (mortality, feed conversion, and so on) differ by production systems. These differences have an effect on production costs, which means that baseline situations had to be calculated for each production system. Health care costs are determined by the prevalence and effect of a disease, both of which differ by production systems. The change in production costs due to a disease regarding a particular production system, that is, absolute effect, was calculated as the difference between the production costs in the baseline situation (healthy) and the production costs in the situation with a particular endemic disease. Calculation of absolute effect only partly enables a comparison between production systems. For a more detailed comparison, 2 relative measures were calculated: the relative effect on production costs and the proportion of the health care costs in total production costs. The relative effect on production costs was determined as the ratio of the increase in production costs due to a disease to production costs in the healthy baseline situation. To obtain the proportion of health care costs in total production costs, the absolute effect was divided by the total production costs in the situation with a particular disease.

Model

The model described by Gocsik et al. (2013) was adapted to calculate the economic effect of a disease; that is, change in production costs under different production systems. The model was adjusted with some technical, economic, and veterinary inputs, such as disease prevalence and effect on production parameters. Stochastic inputs were replaced by deterministic inputs. Production and health care costs were calculated for each delivered broiler in an Excel (Microsoft Corp., Redmond, WA) model using the partial budgeting approach (Dijkhuizen and Morris, 1997).

The model included 4 factors through which disease occurrence might influence productivity and production costs. The negative effects on productivity (losses) as a consequence of a disease occurrence are increased mortality, decreased daily weight gain, increased feed conversion, and an increased condemnation rate at slaughter.

Increase in mortality due to a disease affects the cost of mortality, which was calculated using equation [1]:

$$\text{cost of mortality} = \left\{\begin{array}{l}\text{price day-old chick} + \\ \{[(\text{producer price} \times \text{weight at delivery}) \\ - \text{price day-old chick}]/2\} - \text{cost of delivery}\end{array}\right\} \times (\text{mortality}). \quad [1]$$

The chickens were assumed to die in the middle of the production period. The fixed costs per delivered broiler chicken may change due to an increased mortality because fewer chickens are delivered.

Decrease in daily weight gain affects fixed costs. The chickens were assumed to be kept until they reached the required weight to be delivered. Due to a lower daily weight gain, more days are required to reach the delivery weight. A longer production period results in fewer production rounds per year and, eventually, in a decrease in the number of delivered broiler chickens. Thereby, the fixed costs such as cost of housing and labor per delivered broiler chicken increase.

Increase in feed conversion ratio affects feed costs. Extra feed costs were calculated using equation [2]:

Table 2. Diseases and health problems on the broiler farm

Disease	Cause	Effect on efficiency/production	Effect on business economics[1] Mortality	Growth	Feed	Prevention	Treatment
Respiratory							
Infectious bronchitis[2]	Coronavirus[2]	Mortality due to suffocation[2]	++[3]	-[3]	-[3]	Vaccination, hygiene[2] All-in, all-out system	Good housing conditions and extra heating[4,5]
Immune organs							
Infectious bursal disease[6]	Virus[6]	Mortality[7,8,9] Reduced feed and water intake	+[7,8]	-[9]	-[9]	Vaccination[10,11,12]	No[5,12]
Gastrointestinal							
Coccidiosis[13]	*Eimeria acervulina*[14,15] *Eimeria maxima*[14,15] *Eimeria tenella*[14,15]	Weight loss[16] Reduced growth rate Mortality Increased feed conversion	+[17]	–[18,19]	++[18,19]	Vaccination[20,21,22] Anticoccidial drugs in feed Hygiene (disinfectant)	Chemotherapy Remove wet litter
Escherichia coli (including peritonitis)[23]	*E. coli*[23]	Mortality	+[24]	-[25]	-[26]	Hygiene[23,27] Good ventilation	Antibiotics[26]
Necrotic enteritis[28]	*Clostridium perfringens* type C	Mortality[19,29]	+	-[12]	0	Adjusted feed composition Prevention of coccidiosis General hygiene[5] 10% solution formalin Pre- and probiotics	Antibiotics[5]
Locomotion							
Leg problems[30,31,32]	Genetic predisposition[33] Metabolic disorders Feed composition Lack of movement	Skin irritation and blisters, footpad dermatitis and hock burn Reduced feed intake	0	-[34]	0	Various management factors such as limiting feed, meal feeding, and lighting schedule[31,35,36,37]	No
Heart and vascular							
Ascites[38]	Selection	Condemnation[38] Mortality	++[39]	0	0	Slower growth rate[30] Feed with a lower energy content	No
Sudden death syndrome[40]	Selection	Mortality	++[41]	0	0	Slower growth rate[42,43,44] Feed with a lower energy content	No

[1]– = much lower; - = lower; 0 = equal; + = higher; ++ = much higher. Effect is compared with the healthy situation.
[2]Cavanagh, 2003.
[3]Yohannes et al., 2012.
[4]Lopez et al., 2006.
[5]KWIN-V, 2011.
[6]Lasher and Shane, 1994.
[7]Sanchez et al., 2005.
[8]Cavanagh, 1992.
[9]McIlroy et al., 1989.
[10]BCFI, 2012.
[11]McIlroy et al., 1992.
[12]Saif et al., 2003.
[13]Ruff, 1999.
[14]Graat et al., 1996.

Continued

Table 2 (Continued). Diseases and health problems on the broiler farm

[15]Haug et al., 2008.
[16]Voeten, 2000.
[17]Williams, 1999.
[18]Williams, 1998.
[19]Voeten et al., 1988.
[20]Wheelhouse et al., 1985.
[21]Vermeulen et al., 2001.
[22]Steenhuisen and Vossen, 2001.
[23]Kabir, 2010.
[24]Rahman et al., 2004.
[25]Tian and Baracos, 1989.
[26]Fernandez et al., 1998.
[27]Dziva and Stevens, 2008.
[28]McDevitt et al., 2006.
[29]Brigden and Riddell, 1975.
[30]Julian, 2005.
[31]Estévez, 2007.
[32]De Jong et al., 2012.
[33]Manning et al., 2007.
[34]Weeks et al., 2000.
[35]Su et al., 1999.
[36]Fanatico et al., 2005.
[37]Knowles et al., 2008.
[38]Olkowski et al., 1996.
[39]De Smit et al., 2005.
[40]Newberry et al., 1987.
[41]Julian, 1998.
[42]Havenstein et al., 1994.
[43]Van Horne et al., 2003.
[44]Bricket et al., 2007.

Table 3. Technical inputs by production system

	Production system					
Input variable	Conventional	Volwaard	Better Life 1*/ Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
Full-time labor equivalent	1	1	1	1	1	1
No. of birds	90,000[1]	66,946[2]	58,580[2]	52,073[2]	25,000[3]	25,000[3]
Vacancy[3] (d)	10	10	10	10	10	10
Flocks per year[4] (no.)	7.16	5.5	5.5	5.5	4	4.6
Average daily weight gain[5] (g)	54	41	41	38	35	37
Weight at delivery (g)	2,250[6]	2,300[2]	2,300[2]	2,100[2]	2,800[3]	2,600[3]
Feed conversion rate (g/g)	1.75[2]	2.09[2]	2.09[2]	2.15[2]	2.75[3]	2.63[3]
Mortality (%)	4.0[6]	1.5[6]	1.5[6]	1.5[6]	3.0[3]	2.8[3]

[1]KWIN-V, 2011.

[2]Ellen et al. (2012).

[3]Vermeij and Van Horne (2008).

[4]365/(vacancy + length production period).

[5]Weight at delivery/length production period.

[6]Van Horne et al. (2003).

$$\text{extra feed costs} = \left(\frac{\text{weight at delivery}}{1{,}000}\right) \times \text{feed conversion} \times \text{feed price}. \quad [2]$$

In the above equation, only the feed conversion rate changed as a consequence of the disease, whereas other variables held constant.

Condemnation rate at slaughter affects revenues. If a broiler chicken at the slaughterhouse is rejected, the production costs are already incurred, but little or no revenue is made. The cost of condemnation rate was calculated using equation [3]:

$$\text{cost of condemnation at slaughter} = \left[\text{price day-old chick} + \left(\text{producer price} \times \text{weight at delivery}\right)\right] \times \text{condemnation rate}. \quad [3]$$

The fixed costs per delivered broiler chickens also changed because fewer chickens were delivered. The chickens were assumed to have been rejected as a whole because little or no literature on partial or complete condemnation was available for the diseases concerned (Ellen et al., 2012). Note that birds with leg problems, however, are usually not rejected as a whole. In the Netherlands, the main reasons for rejections are indicated, but rejections are not represented with number per reason of rejection. Carcasses can be rejected for disease and non-disease-related reasons. Due to lack of information on the reasons for rejection, all carcasses are assumed to be rejected for disease-related reasons.

Model Inputs

Technical Inputs. The criteria and requirements of various production systems presented in Table 1 were converted into model inputs (Table 3). Technical inputs were gathered from the literature and represented the average performance of the farms (Van Horne et al., 2003; Vermeij and Van Horne, 2008; Van Horne, 2009; KWIN-V, 2011; Ellen et al., 2012). All farms were assumed to be managed by one full-time labor equivalent (**FTE**).

Veterinary Inputs. In line with the calculation approach described above, production costs were calculated by production system when diseases were absent and present on the farm. Health care costs were determined in conventional and AW systems by the prevalence and effect of the particular disease. A thorough literature review was conducted to collect data on the prevalence and effect of various diseases. In cases where data on AW systems were not available, an expert was consulted to estimate some of the inputs (J.J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication). Estimations regarding the prevalence and effect of various diseases in AW systems were made by relating these inputs to those referring to the conventional system. Although health risk could greatly vary across individual farms, these differences were not taken into account (J.J. de Wit, Dutch Animal Health Service, Deventer, the Netherlands, personal communication). Table 4 presents the prevalence of selected diseases under different production systems.

The requirements of AW concepts may decrease or increase the disease prevalence, but may also affect the effect of the disease on the production parameters. The important production parameters that the disease may affect are mortality, daily weight gain, feed conversion ratio, and condemnation rate at slaughter. Table 5 presents the effect of various diseases.

Economic Inputs. Table 6 presents the economic inputs used to calculate the production costs for each production system. Input data were derived from lit-

Table 4. Prevalence of various diseases and disorders by production systems (%)

	Production system					
Disease	Conventional	Volwaard	Better Life 1*/ Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
IB[1]	0	0	0	0	0	0
IBD	0[2]	0[3]	0[3]	0[3]	0[3]	0[3]
Coccidiosis	34.4[4]	61.6[5]	62.1[6]	62.1[6]	65.5[7]	65.5[7]
E. coli	100[8]	100[9]	100[9]	100[9]	100[10]	100[10]
Necrotic enteritis	12.3[11]	15.7[12]	15.7[12]	15.7[12]	15.7[12]	15.7[12]
Leg problems (gait score >3)	11.35[13]	0.6[14]	0.6[14]	0.6[14]	0[15]	0[15]
Ascites	3.3[16]	1.7[17]	1.7[17]	1.7[17]	0[18]	0[18]
SDS	0.8[19]	0.4[20]	0.4[20]	0.4[20]	0[21]	0[21]

[1]No change in disease prevalence across systems due to vaccination of 1-d-old chicks and a lack of research with regard to risk factors (Cook et al., 1999; Lopez et al., 2006). Re-vaccination is assumed to provide a protection level of 100% against the infectious bronchitis (IB) virus. In case of no vaccination, morbidity in the flock is 90% (Cook et al., 1999; Cavanagh, 2003).

[2]Although Homer et al. (1992) found a prevalence rate of 13.3%, the present study assumed that birds have been vaccinated against infectious bursal disease (IBD), indicating that IBD does not occur on the farm. Cavanagh (2003) suggested that vaccination against IBD provides 100% protection. According to Voeten (2000), vaccination is necessary to prevent loss due to IBD. In this study, IBD vaccination is assumed to provide 100% protection.

[3]No literature has been found indicating an increase in prevalence due to wild birds (Gilchrist, 2005). In the present study, IBD vaccination is assumed to provide 100% protection.

[4]Infection level >50,000 oocysts (Haug et al., 2008).

[5]Free-range area and lower stocking density: 59.1% (Williams et al., 1996). Increase due to a longer daylight period (6 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 2.5%.

[6]Free-range area and lower stocking density: 59.1% (Williams et al., 1996). Increase due to a longer daylight period (8 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 3.0%.

[7]Free-range area, use of prevention drugs prohibited, and lower stocking density: 62.5% (Williams et al., 1996). Increase due to a longer daylight period (8 h): a small increase in coccidiosis is expected due to a longer daylight period, which results in more activity in this period and, in turn, increases the likelihood of picking up oocysts from the environment (Henken et al., 1992). Therefore, the estimated increase in prevalence is 3.0%.

[8]*Escerhichia coli* is assumed to colonize the intestines of all chickens, among other organ systems. The number of chickens in the flock that suffer from symptoms is unknown.

[9]No change in prevalence assumed due to a decrease of cfu in the environment, a lower stocking density, and less dust; however, they do result in a lower impact of the disease.

[10]The number of *E. coli* bacteria increases due to stagnant water in the free-range area, which results in a greater impact of the disease.

[11]Hermans and Morgan (2007).

[12]Free-range area: 28% of the wild birds' feces is infected (Craven et al., 2000). Therefore, the estimated increase compared with the situation without free-range area is 28%.

[13]Fanatico et al. (2008) and Van Horne et al. (2003).

[14]Free-range and lower stocking density (Van Horne et al., 2003).

[15]Slow-growing breed and outdoor access (Fanatico et al., 2008). Effect of daylight is ignored, because leg problems decrease even further due to a longer dark period (Knowles et al., 2008). The effect of stocking density is ignored because the likelihood of having leg problems decreases even further due to a lower stocking density.

[16]Maxwell and Robertson (1998).

[17]The prevalence in case of slow-growing breed is 0. The prevalence in case of a slower-growing breed is assumed to be between 0 and the value of fast-growing breed used in conventional system (1.7). Effect of free-range access: unknown. Natural day-night regimen: increase of 0.6% (Maxwell and Robertson, 1998).

[18]Slow-growing breed: no occurrence of ascites in case of a slow-growing breed (Scheele et al., 2005).

[19]Maxwell and Robertson (1998).

[20]Free-range access results in a decrease in mortality due to sudden death syndrome (SDS; Van Horne et al., 2003). The prevalence of SDS is assumed to decrease as well due to the provision of free-range area.

[21]No SDS in case of slow-growing breed. Natural day-night regimen and provision of free-range area reduces the prevalence of SDS even further (Havenstein et al., 1994; Van Horne et al., 2003; Brickett et al., 2007).

erature (Steenhuisen and Vossen, 2001; Puister, 2009; PVE, 2011; KWIN-V, 2011; Gocsik et al., 2013).

Sensitivity Analysis

Feed price in the broiler sector is highly volatile, which can have a significant effect on the economic performance of the farm. Moreover, the inputs are based on literature and can vary greatly under farm conditions. Therefore, a sensitivity analysis was conducted to evaluate the robustness of the results. The sensitivity analysis was restricted to diseases with the highest economic effect; that is, coccidiosis, *E. coli*, and NE. Feed costs and purchase of 1-d-old chicks are the main drivers of costs (Castellini et al., 2012). Changes in the purchase price of 1-d-old chicks may influence costs through mortality and condemnation at slaughter. Therefore, the feed price, the feed conversion rate, and the purchase price of 1-d-old chicks were systematically varied one at a time. Feed price was changed by

Table 5. Effect of diseases on production performance under different animal welfare (AW) concepts compared with the healthy baseline situation (bolded data indicate that under particular AW concepts the effect of the disease is changed compared with the conventional system)

	Input variable				
Production system/disease	Mortality (% flock)	Daily weight gain (g/d)	Weight at delivery (g)	Feed conversion ratio (g/g)	Condemnation rate at slaughter (% flock)
Conventional					
Baseline situation	4.00[1]	54.88[1]	2,250[1]	1.75[1]	0.00
Infectious bronchitis (IB)	5.00[2]	52.38[2,3]	2,193[2]	1.75[2]	0.50[4]
Infectious bursal disease (IBD)	4.12[5]	52.50[3]	2,205[6]	1.77[6]	0.00
Coccidiosis	4.00[7,8]	51.99[7,8]	2,080[9]	1.87[7,8]	0.00
Coccidiosis with preventive drugs	4.00[7,8]	53.70[7,8,10]	2,008[10]	1.82[10]	0.00
Escherichia coli	4.44[11]	51.62[3]	2,168[12]	1.88[12]	0.00
Necrotic enteritis (NE)	4.82[13]	52.90[3]	2,222[13]	1.82[13]	1.36[13]
Leg problems	4.91[14,15]	44.00[16]	1,848[17]	1.78[18]	0.30[14]
Ascites	4.66[1]	54.88	2,250	1.75	0.26[19]
Sudden death syndrome (SDS)	4.22[1]	54.88[20]	2,250[20]	1.75[20]	0.00
Volwaard					
Baseline situation	1.50[1]	41.07[21]	2,300[22]	2.09[22]	0.00
IB	**1.59[1]**	29.98[2]	2,243[2]	**2.09[2]**	0.50[4]
IBD	**1.62[23]**	40.25[21]	2,254[6]	2.11[6]	0.00
Coccidiosis	1.50[7,8]	**38.92[24]**	**2,180[9]**	**2.21[25]**	0.00
Coccidiosis with preventive drugs	1.50[7,8]	**40.21[24]**	**2,252[10]**	**2.16[10]**	0.00
E. coli	**1.59[11]**	**40.77[21]**	**2,283[26]**	**2.15[26]**	0.00
NE	2.32[13]	40.57[21]	2,272[13]	2.16[13]	1.36[13]
Leg problems	**1.50[1]**	**34.00[16]**	**2,151[16]**	**2.11[18]**	0.30[14]
Ascites	**1.57[1]**	41.07	2,300	2.09	**0.05[19]**
SDS	**1.54[1]**	41.07[20]	2,300[20]	2.09[20]	0.00
Better Life 1*/Puur & Eerlijk					
Baseline situation	1.50[1]	41.07[21]	2,300[22]	2.09[22]	0.00
IB	1.59[1]	29.98[2]	2,243[2]	2.09[2]	0.50[4]
IBD	1.62[23]	40.25[21]	2,254[6]	2.11[6]	0.00
Coccidiosis	1.50[7,8]	38.92[24]	2,180[9]	2.21[25]	0.00
Coccidiosis with preventive drugs	1.50[7,8]	40.21[24]	2,252[10]	2.16[10]	0.00
E. coli	1.59[11]	40.77[21]	2,283[26]	2.15[26]	0.00
NE	2.32[13]	40.57[21]	2,272[13]	2.16[13]	1.36[13]
Leg problems	1.50[1]	34.00[16]	2,151[16]	2.11[18]	0.30[14]
Ascites	1.57[1]	41.07	2,300	2.09	0.05[19]
SDS	1.54[1]	41.07[20]	2,300[20]	2.09[20]	0.00
Better Life 2*					
Baseline situation	1.50[1]	37.50[21]	2,100[22]	2.15[22]	0.00
IB	**1.59[1]**	32.11[2,21]	2,043[2]	2.15[2]	0.50[4]
IBD	**1.62[23]**	36.75[21]	2,058[6]	2.17[6]	0.00
Coccidiosis	1.50[7,8]	**35.92[24]**	**2,012[9]**	**2.27[25]**	0.00
Coccidiosis with preventive drugs	1.50[7,8]	**37.21[24]**	**2,084[10]**	**2.22[10]**	0.00
E. coli	**1.59[11]**	**36.45[21]**	**2,041[26]**	**2.21[26]**	0.00
NE	2.32[13]	37.00[21]	2,072[13]	2.22[13]	1.36[13]
Leg problems	**1.50[1]**	**32.92[16]**	**1,951[16]**	**2.17[18]**	0.30[14]
Ascites	**1.57[1]**	37.50	2,100	2.15	**0.05[19]**
SDS	**1.54[1]**	37.50[20]	2,100[20]	2.15[20]	0.00
Better Life 3*/Skal					
Baseline situation	3.00[27]	34.57[21]	2,800[27]	2.75[27]	0.00
IB	**3.09[1]**	25.55[2]	2,743[2]	2.75[2]	0.50[4]
IBD	**3.12[23]**	33.88[28]	2,744[6]	2.78[6]	0.00
Coccidiosis	3.00[7,8]	**30.25[24]**	**2,450[9]**	**2.87[25]**	0.00
Coccidiosis with preventive drugs	**3.00[11]**	**31.23[28]**	**2,530[29]**	**2.84[29]**	0.00
E. coli	**3.09[11]**	**34.16[28]**	**2,767[26]**	**2.88[26]**	0.00
NE	3.82[13]	34.22[28]	2,772[13]	2.82[13]	1.36[13]
Leg problems	**3.00[1]**	**31.00[16]**	**2,651[16]**	**2.76[18]**	0.30[14]
Ascites	**3.00[1]**	34.57	2,800	2.75	**0.00[19]**
SDS	**3.00[1]**	34.57[20]	2,800[20]	2.75[20]	0.00
Organic					
Baseline situation	2.80[27]	37.14[21]	2,600[27]	2.63[27]	0
IB	**2.89[1]**	36.16[2,30]	2,453[2]	2.63[2]	0.5[4]
IBD	**2.97[1,2]**	36.40[30]	2,548[6]	2.66[6]	0.00
Coccidiosis	2.80[7,8]	**31.50[24]**	**2,205[9]**	**2.75[25]**	0.00
Coccidiosis with preventive drugs	2.80[11]	**32.64[28]**	**2,285[29]**	**2.72[29]**	0.00
E. coli	**3.89[11]**	**36.67[30]**	**2,567[26]**	**2.76[26]**	0.00
NE	3.62[13]	36.74[30]	2,572[13]	2.70[13]	1.36[13]
Leg problems	**2.80[1]**	**33.00[16]**	**2,451[16]**	**2.64[18]**	0.30[14]
Ascites	**2.80[1]**	37.14	2,600	2.63	**0.00[19]**

Continued

Table 5 (Continued). Effect of diseases on production performance under different animal welfare (AW) concepts compared with the healthy baseline situation (bolded data indicate that under particular AW concepts the effect of the disease is changed compared with the conventional system)

	Input variable				
Production system/disease	Mortality (% flock)	Daily weight gain (g/d)	Weight at delivery (g)	Feed conversion ratio (g/g)	Condemnation rate at slaughter (% flock)
SDS	**2.80**[1]	37.14[20]	2,600[20]	2.63[20]	0.00

[1]Van Horne et al. (2003).

[2]Mortality increases by 25%, daily weight gain decreases by 27%; weight at delivery decreases by 57 g; no effect on feed conversion (Yohannes et al., 2012). No difference in impact under AW concepts.

[3]Calculated based on weight at delivery: growth/g per d = weight at delivery/42 d.

[4]Condemnation rate of 0.5%. No change is assumed under AW concepts (Lasher and Shane, 1994).

[5]Mortality increases by 3% in conventional systems (Müller et al., 2003).

[6]Weight at delivery is 2% less; feed conversion increases by 1% (McIlroy et al., 1989).

[7]No mortality due to coccidiosis; daily growth decreases by 1.32 g; weight at delivery is 100 g less, feed conversion increases by 0.1 (Voeten et al., 1988).

[8]No mortality due to coccidiosis; daily growth decreases by 5%; feed conversion increases by 2% (Graat et al., 1998).

[9]Weight at delivery under coccidiosis = average growth/g per d × production days.

[10]Due to coccidiostat, weight at delivery improved to 72 g and the feed conversion decreased by 0.05 compared with the situation in which no vaccination was applied (Wheelhouse et al., 1985).

[11]Mortality under conventional system is 0.26 to 0.62. The average of the 2 seasons is 0.44 (Van Horne et al., 2003). Mortality under the AW concept is 0.09.

[12]Weight at delivery in conventional system is 83 g less; feed conversion was increased by 0.32 g between d 49 to 66, which suggests an increase in feed conversion for approximately 16 d. Accounting for the length of the production round in the conventional system, the feed conversion ratio is estimated at 1.88 g/g, i.e., 16 d × (1.75 g/g + 0.32 g/g) + 24 d × 17.5 g/g (Bhushan et al., 2008).

[13]Mortality increases by 0.82%; weight at delivery is 28 g less; feed conversion increases 0.071, condemnation rate is 1.36% (Lovland and Kaldhusdal, 2001). Under AW concepts, the same effect is assumed as in conventional systems.

[14]Increase in mortality due to leg problems is 0.8%; condemnation rate is 0.3% (Verma, 2007).

[15]Increase in mortality is 1.1% (Sullivan, 1994).

[16]In the study of Yalçin et al. (1998) the daily growth was 7 g less due to leg problems. Hereby, chickens without are compared with those with gait score (GS) 1. The effect in case of GS greater than 3 can be higher, which is also assumed in this study. A decrease in daily growth of 7 g is applied in case of Volwaard, Better Life 1*, and Better Life 2*. The decrease for conventional systems is assumed to be 10 g/d. The decrease for organic and Better Life 3* is assumed to be 4 g/d. Due to the provision of a free-range area, a slower-growing breed, a lower stocking density, and a natural day-night regimen, the number of birds with GS 4 and 5 decreases.

[17]The effect on daily growth is the same for the rest of the production round, which means that the weight at delivery is calculated by multiplying the daily growth by the number of production days.

[18]Chickens with leg problems eat the same quantity (Weeks et al., 2000). However, these chickens lose weight, which results in a higher feed conversion. Su et al. (1999) calculated the feed conversion for chickens with and without GS 4 and 5. The average feed conversion for chickens with GS 4 and 5 was 0.03 lower than that in the situation without leg problems. With improved welfare, the severity of leg problems decreases. It is assumed that leg problems are the most severe in the conventional system, which indicates that leg problems have the highest effect on feed conversion in conventional systems (feed conversion is lower with 0.03). In Volwaard, Better Life 1*, and Better Life 2*, the feed conversion was 0.02 lower and in Better Life 3* and organic systems it was 0.01 lower compared with the situation without leg problems.

[19]Condemnation rate for conventional is 0.26%. Condemnation rate for AW concepts is 0.05%. However, no ascites are assumed for organic and Better Life 3* systems, which means that the condemnation rate under these concepts is zero (Herenda and Jakel, 1994).

[20]No effect apart from mortality (Julian, 2005).

[21]Calculated based on weight at delivery: growth/g per d = weight at delivery/56 d.

[22]Ellen et al. (2012).

[23]Mortality due to IBD increases similarly under AW and conventional systems (+0.12). This results in a relative increase in mortality due to IBD, which corresponds to the findings of Van Horne et al. (2003).

[24]Voeten et al. (1988) found that chickens could recover from an infection of coccidiosis in 35 d, which means that its effect on performance was eliminated. It is assumed that the chicken grows at a slower rate for 35 d, and for the rest of production period, a healthy growth rate is calculated. The following formula calculates the average growth: average growth/g per d = [35 d recovery × (growth healthy – negative effect coccidiosis) + rest of the production period × growth healthy]/total production days. Under Volwaard, Better Life 1*, and Better Life 2*, the daily growth decreases by 4 g/d lower during the recovery period of 35 d. Under Better Life 3* and organic, the daily growth decreases by 11 g/d, because the free-range area infection with coccidiosis and the probability of picking up more oocysts increase.

[25]Subclinical coccidiosis is primarily expected in a conventional system. A light infection level is assumed in Volwaard, Better Life 1*, and Better Life 2* because the chickens have access to free range. A moderate infection level is assumed in Better Life 3* and organic systems because the use of anticoccidial drugs is prohibited (Reid and Johnson, 1970; Voeten et al., 1988).

[26]Effect of *E. coli* is decreased due to a lower stocking density, breed, and fewer stress factors. However, there is an increase due to the free-range area. The relative decrease in mortality is calculated (80%) according to Van Horne et al. (2003). The effect under the AW concepts is decreased by 80% compared with that under conventional system. However, in case of organic and Better Life 3* concepts, the free-range area is not covered and the water may remain there, which could serve as a good reserve for *E. coli*. Therefore, the effect of *E. coli* for these concepts is decreased by 60%.

[27]Vermeij and Van Horne (2008).

[28]Calculated based on weight at delivery: growth/g per d = weight at delivery/81 d.

[29]Due to vaccination against coccidiosis, weight at delivery improved to 80 g and the feed conversion decreased by 0.03 compared with the situation in which no vaccination was applied (Vermeulen et al., 2001).

[30]Calculated based on weight at delivery: growth/g per d = weight at delivery/70 d.

Table 6. Economic inputs by different production systems

Input variable	Production system					
	Conventional	Volwaard	Better Life 1*/Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
Feed price[1] (€/100 kg)	31.839	30.883	30.883	30.883	45.211	45.211
Price of 1-d-old chick[1] (€/chick)	0.302	0.320	0.320	0.320	0.438	0.438
Litter[1] (€/chicken)	0.008	0.030	0.028	0.026	0.040	0.040
Product board levies[2] (€/100 chickens)	0.290	0.290	0.290	0.290	0.290	0.290
Carrion collecting service[2] (€/100 chickens)	0.200	0.200	0.200	0.200	0.200	0.200
Manure disposal[2] (€/100 chickens)	2.400	2.400	2.400	2.400	2.400	2.400
Labor cost[2] (h)	25.00	25.00	25.00	25.00	25.00	25.00
Electricity[1] (€/chicken)	0.023	0.023	0.023	0.023	0.012	0.012
Heating[1] (€/chicken)	0.045	0.068	0.068	0.068	0.090	0.090
Coccidiostat[3] (€/chicken)	0.007	0.007	0.007	0.007	0.007	0.007
Vaccination coccidiosis[4] (€/chicken)	0.120	0.120	0.120	0.120	0.120	0.120
Vaccination IBD[5] (€/chicken)	0.010	0.010	0.010	0.020	0.020	0.020
Re-vaccination IB[5] (€/chicken)	0.010	0.010	0.010	0.010	0.010	0.010
Antibiotic treatment NE and *Escherichia coli*[3,6] (€/chicken)	0.027	0.027	0.027	0.027	0.027	0.027
Fixed costs[2] (%)						
Depreciation of buildings	4	4	4	4	4	4
Depreciation inventory	8	8	8	8	8	8
Interest	5	5	5	5	5	5
Interest livestock	6	6	6	6	6	6
Maintenance of buildings	1	1	1	1	1	1
Maintenance inventory	2	2	2	2	2	2
Maintenance outdoor access	2	2	2	2	2	2

[1]Gocsik et al. (2013).
[2]KWIN-V (2011).
[3]Puister (2009). NE = necrotic enteritis.
[4]Steenhuisen and Vossen (2001).
[5]Standard tariff for Dutch veterinarians. IBD = infectious bursal disease; IB = infectious bronchitis.
[6]PVE (2011).

±5%, feed conversion by ±0.1, and purchase price of 1-d-old chicks by ±5%.

RESULTS

Absolute Effect of Various Diseases on Production Costs

Table 7 presents the absolute effect of various diseases on production costs. During the calculation of production costs, one disease was considered at a time and no interaction effect between diseases was assumed. Production costs in the baseline situation (no diseases) differed across systems. With regard to production costs, 3 categories emerged. The first category included the conventional system with the lowest production costs. The second category, which included Volwaard, Better Life 1*, and Better Life 2* (also referred to as middle-market systems), produced costs that were higher than the conventional system, but considerably lower than systems in the third category, which included Better Life 3* and organic.

In the conventional system, diseases that affect the gastrointestinal tract (that is, *E. coli* and NE) had the highest absolute effect on production costs. Production costs per delivered broiler increased by €0.144 in case of *E. coli* and by €0.071 in case of NE. The other diseases had a minor effect on production costs. Similarly, in case of the second category, *E. coli* and NE again had the highest effect on production costs, whereas, in the third category, coccidiosis had the highest effect, followed by *E. coli* and NE. The high effect of coccidiosis can be explained by the fact that the use of anticoccidial drugs is prohibited in organic systems. The absolute effect of gastrointestinal problems on production costs remained at the same level or even increased with more welfare-friendly production. However, the absolute effect of leg problems and heart and vascular disease decreased for AW systems because these systems use a more robust breed.

Relative Effect of Various Diseases on Production Costs

Table 8 shows the relative effect of various diseases on production costs. Again, the same 3 categories emerged as in the case of absolute effect.

In the conventional system, the highest relative effect was caused by gastrointestinal diseases corresponding to approximately 11.5%, which was the sum of separate effects (i.e., coccidiosis = 1.24%, *E. coli* = 6.8%, NE = 3.39%), followed by leg problems. The dominance of gastrointestinal diseases in terms of relative effect can be recognized in all systems. In the second category (which included Volwaard, Better Life 1*, and Better Life 2*), the relative effect of gastrointestinal diseases

Table 7. Production costs per delivered broiler in the baseline situation and situation with an endemic disease and absolute effect on production costs compared with the baseline situation (€)

Disease[1]	Conventional Production cost	Conventional Absolute effect	Volwaard Production cost	Volwaard Absolute effect	Better Life 1*/ Puur & Eerlijk Production cost	Better Life 1*/ Puur & Eerlijk Absolute effect	Better Life 2* Production cost	Better Life 2* Absolute effect	Better Life 3*/Skal Production cost	Better Life 3*/Skal Absolute effect	Organic Production cost	Organic Absolute effect
Baseline situation	2.094	0.000	2.586	0.000	2.700	0.000	2.614	0.000	6.075	0.000	5.291	0.000
Respiratory												
IB	2.104	0.010	2.596	0.010	2.710	0.010	2.624	0.010	6.085	0.010	5.301	0.010
Immune organs												
IBD	2.104	0.010	2.596	0.010	2.710	0.010	2.634	0.020	6.095	0.020	5.311	0.020
Gastrointestinal												
Coccidiosis	2.120	0.026	2.630	0.044	2.746	0.046	2.652	0.039	6.320	0.245	5.522	0.232
Escherichia coli	2.238	0.144	2.661	0.075	2.776	0.076	2.699	0.086	6.291	0.215	5.522	0.231
NE	2.165	0.071	2.672	0.087	2.787	0.087	2.697	0.083	6.222	0.147	5.429	0.138
Locomotion												
Leg problems	2.119	0.025	2.595	0.009	2.709	0.009	2.622	0.008	6.075	0.000	5.291	0.000
Heart and vascular												
Ascites	2.107	0.013	2.588	0.002	2.703	0.003	2.617	0.003	6.075	0.000	5.291	0.000
SDS	2.098	0.004	2.586	0.001	2.701	0.001	2.615	0.001	6.075	0.000	5.291	0.000

[1]IB = infectious bronchitis; IBD = infectious bursal disease; NE = necrotic enteritis; SDS = sudden death syndrome.

was lower (approximately 8%) than in the conventional system. In the third category, however, their relative effect was almost at the same level as that in the conventional system. The effect of leg problems decreased with increasing AW standards. The relative effect of other diseases remained below 1% in all systems, which meant they were less important in that regard.

Proportion of Health Care Costs in Total Production Costs

Table 9 lists the health care costs due to gastrointestinal diseases and leg problems as a percentage of total production costs. These diseases were selected because they had the highest relative effect on production costs (as shown in Table 8). Health care costs were split into L and E and presented as percentage shares of the total production costs.

As Table 9 shows, health care costs represent only a small share of total production costs in all systems. In conventional and middle-market systems, the proportion of loss within total health care costs is approximately 3 times greater than the proportion of expenditures. In Better Life 3* and organic systems, the proportion of loss is approximately 90% of the total health care costs. However, in case of coccidiosis, health care costs were solely derived from loss (100%) in these 2 systems, whereas in conventional systems, 73% of health care costs came from loss. This larger loss due to coccidiosis in Better Life 3* and organic systems occurred because the use of anticoccidal drugs was prohibited, which meant that procuring them incurred no expenditures. In general, the proportion of loss in total health care costs is larger than that of expenditures. Because the symptoms of gastrointestinal diseases remain subclinical, these diseases usually remain untreated. For example, a less efficient feed conversion due to a gastrointestinal disease results in a higher feed consumption and, ultimately, in higher feed costs. This implies that it is more difficult to detect the actual effect of these diseases because they are not incurred as direct expenditures. The loss due to leg problems decreased in the middle-market systems due to increasing AW standards. In the organic system, no health care costs occurred due to leg problems.

Sensitivity Analysis

Because it was of great importance that the ranking of production systems for various diseases is robust to changes in input values, changes in relative effect were studied. Accordingly, we analyzed changes in the sequence from the highest to the lowest relative effect. Table 10 shows that irrespective to changes in the variables included in the analysis, coccidiosis had the highest relative effect in the organic system and the lowest relative effect in the conventional system. *Escherichia coli* had the highest relative effect in the conventional

Table 8. Relative effect of various diseases on production costs per delivered broiler (%)

	Production system					
Disease[1]	Conventional	Volwaard	Better Life 1*/Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
Baseline situation	0.00	0.00	0.00	0.00	0.00	0.00
Respiratory						
IB	0.48	0.39	0.37	0.38	0.16	0.19
Immune organs						
IBD	0.48	0.39	0.37	0.77	0.33	0.38
Gastrointestinal						
Coccidiosis	1.24	1.70	1.68	1.48	4.03	4.38
Escherichia coli	6.86	2.89	2.80	3.28	3.54	4.37
NE	3.39	3.25	3.22	3.18	2.42	2.61
Locomotion						
Leg problems	1.19	0.35	0.33	0.31	0.00	0.00
Heart and vascular						
Ascites	0.61	0.10	0.09	0.11	0.00	0.00
SDS	0.19	0.02	0.02	0.04	0.00	0.00

[1]IB = infectious bronchitis; IBD = infectious bursal disease; NE = necrotic enteritis; SDS = sudden death syndrome.

system and the lowest effect in the Better Life 1* system. Similarly, NE had the highest relative effect in the conventional system and the lowest effect in the Better Life 3* system under all of the examined conditions. Overall, the results indicated that changes in feed price, feed conversion, and purchase price of 1-d-old chicks had no effect on the sequence from the highest to the lowest relative effect.

DISCUSSION

The aim of the study was to analyze the effect of different broiler production systems on readily quantifiable health care costs, which were calculated per delivered broiler using partial budgeting. A model described by Gocsik et al. (2013) was used and adapted to calculate health care costs in Dutch broiler production systems.

Although the approach used in our study draws heavily on input data that were not available in peer-reviewed scientific literature, all input data were gathered with care and thoroughly checked with an expert in poultry diseases to be able to provide the most accurate results.

The approach used in our study involved certain approximations and assumptions. First, own labor cost was assumed to be fixed. A farm was assumed to have as many animal places as can be managed by one FTE. When diseases occur, the activities on the farm may require more time than the farmer has available and extra personnel may have to be hired, potential causing health care costs to increase. The literature on time spent on treatment and hygiene measures as a consequence of a disease occurrence is scarce. The broiler farmer was assumed to have time available to perform these activities. Second, the default values used in this

Table 9. Proportion of health care costs within the total production costs (%) and proportion of loss (L) and expenditures (E) expressed as a percentage in total production costs

	Production system					
Disease	Conventional	Volwaard	Better Life 1*/Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
Gastrointestinal						
Coccidiosis[1]	1.22	1.68	1.65	1.46	3.88	4.20
L	0.89	1.42	1.41	1.20	3.88	4.20
E	0.33	0.26	0.24	0.26	—	—
Escherichia coli[1]	6.42	2.81	2.72	3.18	3.42	4.19
L	5.22	1.81	1.77	2.18	2.99	3.70
E	1.21	1.00	0.96	1.00	0.43	0.49
NE[1]	3.28	3.24	3.12	3.08	2.36	2.55
L	2.04	2.24	2.17	2.08	1.93	2.05
E	1.25	0.99	0.95	1.00	0.43	0.50
Locomotion						
Leg problems[1]	1.18	0.34	0.33	0.31	0.00	0.00
L	1.18	0.34	0.33	0.31	—	—
E	—	—	—	—	—	—

[1]C = L + E. Health care costs (C) consists of loss (L) caused by diseases and the preventive and treatment expenditures (E).

Table 10. Relative effect of various diseases on production costs per delivered broiler in case of changes in feed price, feed conversion ratio, and price of 1-d-old chicks

		Production system					
Disease	Change in variable	Conventional	Volwaard	Better Life 1*/Puur & Eerlijk	Better Life 2*	Better Life 3*/Skal	Organic
	Feed price (%)						
Baseline situation	−5	0.00	0.00	0.00	0.00	0.00	0.00
	0	0.00	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00	0.00
Coccidiosis	−5	1.23	1.71	1.72	1.42	4.06	4.42
	0	1.24	1.70	1.70	1.45	4.03	4.37
	5	1.30	1.69	1.73	1.42	3.95	4.33
Escherichia coli	−5	6.86	2.91	2.78	3.23	3.51	4.36
	0	6.86	2.90	2.81	3.25	3.56	4.37
	5	6.92	2.90	2.78	3.21	3.57	4.39
NE[1]	−5	3.50	3.43	3.28	3.27	2.47	2.69
	0	3.39	3.33	3.22	3.18	2.42	2.61
	5	3.39	3.27	3.14	3.09	2.35	2.55
	Feed conversion ratio						
Baseline situation	−0.1	0.00	0.00	0.00	0.00	0.00	0.00
	0	0.00	0.00	0.00	0.00	0.00	0.00
	+0.1	0.00	0.00	0.00	0.00	0.00	0.00
Coccidiosis	−0.1	1.34	1.75	1.71	1.45	4.12	4.49
	0	1.24	1.70	1.70	1.45	4.03	4.37
	+0.1	1.20	1.66	1.62	1.38	3.95	4.31
E. coli	−0.1	7.17	2.98	2.85	3.33	3.61	4.49
	0	6.88	2.90	2.81	3.25	3.56	4.37
	+0.1	6.60	2.79	2.71	3.13	3.47	4.29
NE	−0.1	3.51	3.42	3.27	3.26	2.47	2.69
	0	3.39	3.33	3.22	3.18	2.42	2.61
	+0.1	3.28	3.24	3.14	3.10	2.37	2.57
	Price of 1-d-old chicks (%)						
Baseline situation	−5	0.00	0.00	0.00	0.00	0.00	0.00
	0	0.00	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00	0.00
Coccidiosis	−5	1.25	1.71	1.68	1.42	4.05	4.38
	0	1.24	1.70	1.70	1.45	4.03	4.37
	5	1.23	1.69	1.66	1.41	4.02	4.35
E. coli	−5	6.88	2.92	2.83	3.27	3.55	4.37
	0	6.88	2.90	2.81	3.25	3.56	4.37
	5	6.78	2.88	2.76	3.19	3.53	4.35
NE	−5	3.42	3.35	3.24	3.19	2.41	2.60
	0	3.39	3.33	3.22	3.18	2.42	2.61
	5	3.36	3.31	3.20	3.15	2.41	2.60

[1]NE = necrotic enteritis.

study, such as weight at delivery and feed conversion rate, were averages representing the Netherlands and thus country specific. It is unknown whether and to what extent these values were influenced by diseases. No corrections were made in this respect, which means that these values may differ in practice. However, this assumption is not expected to influence the results considerably because it was valid for all systems. Further, only the direct disease effects were taken into account, in other words the possible immunosuppressive effect of some diseases was not considered. Third, no interactions were assumed between diseases because, for most diseases, it is still unclear whether and to what extent the effect of the diseases changes in case 2 endemic diseases simultaneously occur in the flock (Cavanagh, 2003; Matthijs et al., 2003). Fourth, we assumed that vaccination against IB and IBD would protect the flock 100% and that these diseases would no longer occur on the farm. In case of IBD, however, the hygienic status of the farm is known to influence the effectiveness of the vaccine (Müller et al., 2012). Moreover, little is known about whether the vaccine offers cross-protection against other serotypes. A farm with an outdoor area for chickens is expected to have a lower level of hygiene, which negatively affects the effectiveness of the vaccine. Moreover, chickens in an organic farm have more antibodies against IBD than chickens in conventional farms (Van Overbeke et al., 2006). Hence, in case of farms with Better Life 2*, Better Life 3*, and organic systems, which have an increased risk of IBD, a more expensive vaccination program was assumed to be implemented. Because a vaccine against IB may not provide 100% protection either (Cavanagh, 2003), chickens were assumed to be vaccinated twice. The study investigates the health care costs of the preventive measures, not the economic feasibility. In other words, if vaccination prevented great losses, it was chosen as a preventive measure. Fifth, the chickens were assumed to be equally susceptible and sensitive to the diseases throughout the entire growth period. The effect of current breeder health programs is implicitly taken into account, because the prevalence and effect of diseases were determined based on the current production systems and the characteristics of breeds currently used in practice. This model does not take potential resistance against preventive drugs and antibiotics into account. However, coccidiosis is known to be more and more resistant against anticoccidial drugs, which mitigates the negative effects of diseases to a lesser extent (Jenkins et al., 2010). Hence, avoidable costs might be lower than those estimated in the model. Resistance to drugs against NE and *E. coli* has also been increasing. In each system, the same amount of drugs was assumed to be used. The study did not include the potential effect of a particular disease in previous and subsequent production rounds. Sixth, health care costs may have been overestimated to some extent. A disease has an effect on the production function, and therefore on the optimal production level (McInerney, 1996). An economically rational farmer would minimize the effect of a disease by adjusting the level of input use, which would probably result in health care costs lower than those estimated in this study. Finally, figures for prevalence and effect might not entirely reflect the latest developments in broiler production. For example, in recent years the incidence of ascites has reduced due to including ascites in the selection index; however, recent figures cannot be found in literature. As a consequence, the actual values for prevalence may be lower than those we used in our calculation. However, this holds for all systems. Therefore, the differences between systems remain similar. In other words, whereas actual costs due to ascites may be lower, the relative differences between systems remain unchanged. Moreover, due to various assumptions and estimations, production costs may be under- or overestimated. Therefore, it is important that these costs are not used as indicators, but to comprehensively assess the differences between systems. Sensitivity analysis showed that ranking of production systems is robust to changes in feed price, feed conversion, and price of 1-d-old chicks.

To our knowledge, this study is the most extensive attempt to compare AW systems on the basis of their health care costs. The results of the study show that health care costs represent only a small proportion of total production costs, regardless of the production system. Losses account for the majority of health care costs, which makes the actual effect of diseases on total health care costs difficult to detect. Three categories of production systems were distinguished based on health care costs. The first category includes conventional systems, in which diseases affecting the gastrointestinal tract and leg problems had the highest effect on production costs in both absolute and relative terms. Similarly, in the second category, referred to as middle-market systems, gastrointestinal diseases and leg problems had the highest effect on production costs. However, the effect of these diseases was lower than that of diseases in conventional system. The decrease in effect can be explained by the fact that these AW systems use a more robust breed with a slower growth rate. In the third category, gastrointestinal diseases had the highest effect and the overall effect of gastrointestinal diseases was similar to that in the conventional system. However, the effect of coccidiosis increased compared with the conventional system, most likely due to prohibition on the use of anticoccidial drugs and the provision of an outdoor access. Moreover, leg problems and heart and vascular diseases disappeared completely, which is probably the result of the use of a more robust breed with a slower growth rate. Angel (2007) suggested that chickens with slower early growth rate have less problems with skeletal development. Also, research indicated that there was a direct correlation between high growth rate and ascites (European Commission, 2000).

There are only a few studies against which to compare our results. Vermeij (2004) and Vermeij and Van Horne (2008) calculated cost-prices for organic broiler farms in 2004 and in 2008. The total health care costs were estimated at €0.12 per broiler in 2004 and €0.10 per broiler in 2008. These estimates do not agree with the results of this study, in which the absolute health care costs are often higher than €0.10 per delivered broiler in an organic farm. Lovland and Kaldhusdal (2001) found that the profit margin decreased by 33% in case of high levels of NE in the flock compared with low levels of the disease. Moreover, the absolute costs due to NE in the United States were estimated at US$0.05 per broiler chicken (McDevitt et al., 2006). In another American study, the loss ranged between $878.19 and $1,480.52 per flock of 20,000 broilers. This works out to an estimated $0.044 to 0.074 per chicken (Skinner et al., 2010), which, based on exchange rates at the time of writing, equates to approximately €0.03 to 0.06 per broiler. This is in agreement with the results of the conventional system. However, these costs are much higher in Better Life 3* and organic systems. Lund and Algers (2003) supported the findings of this study. Based on a literature study, they concluded that the level of animal health in an organic farm was the same or slightly lower level than in a conventional system, except for (endo-)parasitic infections, which occurred more often in an organic farm. The occurrence of other diseases remained at the same level or decreased compared with a conventional system. This difference can also be found in the results of the present study. In other words, the occurrence of parasitic infections, such as coccidiosis, increases compared with a conventional system, whereas the occurrence of other diseases, such as leg problems, SDS, and ascites, decreases.

Although the study focused on the Dutch situation, the findings are relevant for countries that face similar concerns with respect to AW than the Netherlands (for example, other European Union countries and United

States) and develop their production in a similar direction than the Netherlands (for example, France and United Kingdom; Gocsik et al., 2013).

Although we observed that particular health care costs increase as the assumed level of AW increases, this finding does not apply to all diseases. We conclude that, although differences in health care costs exist across production systems, health care costs have only a minor role within the total production costs relative to other costs, such as feed costs and purchase of 1-d-old chicks. Therefore, the effect of health care costs on farmers' strategic decisions regarding the production system is most likely to be outweighed by other costs.

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REFERENCES

Angel, R. 2007. Metabolic disorders: Limitations to growth of and mineral deposition into the broiler skeleton after hatch and potential implications for leg problems. J. Appl. Poult. Res. 16:138–149. http://dx.doi.org/http://dx.doi.org/ 10.1093/japr/16.1.138.

BCFI. 2012. Vaccinatie van kippen. Accessed Oct. 19, 2012. http://www.cbip-vet.be/nl/texts/NAVOOOL1AL2o.php#Kippen.

Bennett, R. 2003. The 'Direct Costs' of Livestock Disease: The development of a system of models for the analysis of 30 endemic livestock diseases in Great Britain. J. Agric. Econ. 54:55–71. http://dx.doi.org/10.1111/j.1477-9552.2003.tb00048.x.

Bennett, R., and J. Ijpelaar. 2005. Updated estimates of the costs associated with thirty four endemic livestock diseases in Great Britain: A note. J. Agric. Econ. 56:135–144. http://dx.doi.org/10.1111/j.1477-9552.2005.tb00126.x.

Bergevoet, R. H. M., J. C. M. Bartels, J. Van Der Goot, and M. Wolthuis-Fillerup. 2010. Bedrijfsgebonden dierziekten op varkens-, rundvee en pluimveebedrijven. Inventarisatie en prioritering van de belangrijkste aandoeningen. Rapport 384. Wageningen UR Livestock Research, Lelystad, The Netherlands. Accessed Nov. 22, 2013. http://edepot.wur.nl/160695.

Bhushan, B., S. K. Garg, and J. Kumar. 2008. Effect of a polyherbal feed supplement on production performance and nutrient utilization in *Escherichia coli* challenged broiler chicks. Indian J. Vet. Res. 17:27–36.

Blokhuis, H. J., R. B. Jones, R. Geers, M. Miele, and I. Veissier. 2003. Measuring and monitoring animal welfare: Transparency in the food product quality chain. Anim. Welf. 12:445–455.

Brickett, K. E., J. P. Dahiya, H. L. Classen, C. B. Annett, and S. Gomis. 2007. The effect of nutrient density, feed form, and photoperiod on the walking ability and skeletal quality of broiler chickens. Poult. Sci. 86:2117–2125.

Brigden, J. L., and C. Riddell. 1975. A survey of mortality in four broiler flocks in western Canada. Can. Vet. J. 16:194–200.

Castellini, C., A. Boggia, C. Cortina, A. Dal Bosco, L. Paolotti, E. Novelli, and C. Mugnai. 2012. A multicriteria approach for measuring the sustainability of different poultry production systems. J. Clean. Prod. 37:192–201. http://dx.doi.org/10.1016/j.jclepro.2012.07.006.

Cavanagh, D. 1992. Recent advances in avian virology. Br. Vet. J. 148:199–222.

Cavanagh, D. 2003. Severe acute respiratory syndrome vaccine development: Experiences of vaccination against avian infectious bronchitis coronavirus. Avian Pathol. 32:567–582. http://dx.doi.org/10.1080/0307945031000162119 8.

Cook, J. K. A., S. J. Orbell, M. A. Woods, and M. B. Huggins. 1999. Breadth of protection of the respiratory tract provided by different live-attenuated infectious bronchitis vaccines against challenge with infectious bronchitis viruses of heterologous serotypes. Avian Pathol. 28:477–485. http://dx.doi.org/10.1080/03079459994506.

Craven, S. E., N. J. Stern, E. Line, J. S. Bailey, N. A. Cox, and P. Fedorka-Cray. 2000. Determination of the incidence of *Salmonella* spp., *Campylobacter jejuni*, and *Clostridium perfringens* in wild birds near broiler chicken houses by sampling intestinal droppings. Avian Dis. 44:715–720. http://dx.doi.org/10.2307/1593118.

Cui, S., B. Ge, J. Zheng, and J. Meng. 2005. Prevalence and antimicrobial resistance of *Campylobacter* spp. and *Salmonella* serovars in organic chickens from Maryland retail stores. Appl. Environ. Microbiol. 71:4108–4111.

De Jong, I., C. Berg, A. Butterworth, and I. Estévez. 2012. Scientific report updating the EFSA opinions on the welfare of broilers and broiler breeders. Supporting Publications 2012:EN-295. Accessed Nov. 22, 2013. http://www.efsa.europa.eu/en/supporting/pub/295e.htm.

De Smit, L., K. Tona, V. Bruggeman, O. Onagbesan, M. Hassanzadeh, L. Arckens, and E. Decuypere. 2005. Comparison of three lines of broilers differing in ascites susceptibility or growth rate, egg weight loss, gas pressure, embryonic heat production and physiological hormone levels. Poult. Sci. 84:1446–1452.

Dijkhuizen, A. A., and R. S. Morris. 1997. Animal health economics: Principles and applications. Post Graduate Foundation in Veterinary Science, University of Sydney, Sydney, Australia.

Dziva, F., and M. P. Stevens. 2008. Colibacillosis in poultry: Unravelling the molecular basis of virulence of avian pathogenic *Escherichia coli* in their natural hosts. Avian Pathol. 37:355–366.

EC. 2007a. Regulation (EC) No. 834/2007, OJ L 189, p. 1 of 20.7.2007. Accessed Nov. 25, 2013. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:189:0001:0023:EN:PDF.

EC. 2007b. Directive, 2007/43/EC, OJ L 182, p. 19 of 12.7.2007. Accessed Nov. 25, 2012. http://eur-lex.europa.eu/LexUriServ/site/en/oj/2007/l_182/l_18220070712en00190028.pdf.

EC. 2008. Regulation (EC) No. 543/2008, OJ L 157, p. 46 of 17.6.2008. Accessed Nov. 25, 2012. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:157:0046:0087:EN:PDF.

Ellen, H., F. Leenstra, R. van Emous, K. Groenestein, J. van Harn, P. van Horne, I. De Jong, M. Kense, D. Mevius, and J. A. Wagenaar. 2012. Vleeskuikenproductiesystemen in Nederland, Rapport 619 (in Dutch with English summary). Livestock Research, Wageningen University and Research Centre, Lelystad, the Netherlands.

Estévez, I. 2007. Density allowance for broilers: Where to set limits? Poult. Sci. 86:1265–1272.

European Commission. 2000. The welfare of chickens kept for meat production (broilers). Scientific Committee on Animal Health and Animal Welfare. Accessed Nov. 22, 2013. http://ec.europa.eu/food/fs/sc/scah/out39_en.pdf.

Fanatico, A. C., P. B. Pillai, L. C. Cavitt, C. M. Owens, and J. L. Emmert. 2005. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Growth performance and carcass yield. Poult. Sci. 84:1321–1327.

Fanatico, A. C., P. B. Pillai, P. Y. Hester, C. Falcone, J. A. Mench, C. M. Owens, and J. L. Emmert. 2008. Performance, livability, and carcass yield of slow- and fast-growing chicken genotypes fed low-nutrient or standard diets and raised indoors or with outdoor access. Poult. Sci. 87:1012–1021. http://dx.doi.org/10.3382/ps.2006-00424.

Fernandez, A., C. Lara, R. Puyuelo, J. Gomez, J. J. Ramos, A. Loste, M. C. Marca, and M. T. Verde. 1998. Efficacy of phosphomycin in the control of *Escherichia coli* infection of broiler chickens. Res. Vet. Sci. 65:201–204.

Fraser, D. 2006. Animal welfare assurance programs in food production: A framework for assessing the options. Anim. Welf. 15:93–104.

GD. 2012. Vaccinatieschema. Accessed Oct. 19, 2012. http://www.gddeventer.com/pluimvee/voor%20dierhouders/diergezondheid/~/media/Files/pluimvee%20vaccinatieschemas/vaccinatiekrt%20vleeskuikens.pdf.ashx.

Gilchrist, P. 2005. Involvement of free-flying wild birds in the spread of the viruses of avian influenza, Newcastle disease and infectious bursal disease from poultry products to commercial poultry. World's Poult. Sci. J. 61:198–214. http://dx.doi.org/10.1079/WPS200451.

Gocsik, É., A. G. J. M. Oude Lansink, and H. W. Saatkamp. 2013. Mid-term financial effect of animal welfare improvements in Dutch broiler production. Poult. Sci. 92:3314–3329.

Graat, E. A. M., H. W. Ploeger, A. M. Henken, G. de Vries Reilingh, J. P. T. M. Noordhuizen, and P. N. G. M. van Beek. 1996. Effects of initial litter contamination level with *Eimeria acervulina* on population dynamics and production characteristics in broiler. Vet. Parasitol. 65:223–232.

Graat, E. A. M., E. van der Kooij, K. Frankena, A. M. Henken, J. F. M. Smeets, and M. T. J. Hekerman. 1998. Quantifying risk factors of coccidiosis in broilers using on-farm data based on a veterinary practice. Prev. Vet. Med. 33:297–308. http://dx.doi.org/10.1016/S0167-5877(97)00008-1.

Haug, A., A.-G. Gjevre, E. Skjerve, and M. Kaldhusdal. 2008. A survey of the economic effect of subclinical *Eimeria* infections in broiler chickens in Norway. Avian Pathol. 37:333–341. http://dx.doi.org/10.1080/03079450802050705.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994. Growth, livability, and feed conversion of 1957 vs 1991 broilers when fed "typical" 1957 and 1991 broiler diets. Poult. Sci. 73:1785–1794. http://dx.doi.org/10.3382/ps.0731785.

Henken, A. M., J. O. Goelema, F. Neijenhuis, M. H. Vertommen, J. Van Den Bos, and C. Fris. 1992. Multivariate epidemiological approach to coccidiosis in broilers. Poult. Sci. 71:1849–1856. http://dx.doi.org/10.3382/ps.0711849.

Herenda, D., and O. Jakel. 1994. Poultry abattoir survey of carcass condemnation for standard, vegetarian, and free range chickens. Can. Vet. J. 35:293–296.

Hermans, P. G., and K. L. Morgan. 2007. Prevalence and associated risk factors of necrotic enteritis on broiler farms in the United Kingdom; a cross-sectional survey. Avian Pathol. 36:43–51. http://dx.doi.org/10.1080/03079450601109991.

Homer, B. L., G. D. Butcher, R. D. Miles, and A. F. Rossi. 1992. Subclinical infectious bursal disease in an integrated broiler production operation. J. Vet. Diagn. Invest. 4:406–411. http://dx.doi.org/10.1177/104063879200400406.

Houe, H. 2003. Economic effect of BVDV infection in dairies. Biologicals 31:137–143. http://dx.doi.org/10.1016/S1045-1056(03)00030-7.

Jenkins, M., S. Klopp, D. Ritter, K. Miska, and R. Fetterer. 2010. Comparison of *Eimeria* species distribution and Salinomycin resistance in commercial broiler operations utilizing different coccidiosis control strategies. Avian Dis. 54:1002–1006.

Julian, R. J. 1998. Rapid growth problems: Ascites and skeletal deformities in broilers. Poult. Sci. 77:1773–1780.

Julian, R. J. 2005. Production and growth related disorders and other metabolic diseases of poultry—A review. Vet. J. 169:350–369. http://dx.doi.org/10.1016/j.tvjl.2004.04.015.

Kabir, S. M. L. 2010. Review: Avian colibacillosis and Salmonellosis: A closer look at epidemiology, pathogenesis, diagnosis, control and public health concerns. Int. J. Environ. Res. Public Health 7:89–114.

Knowles, T. G., S. C. Kestin, S. M. Haslam, S. N. Brown, L. E. Green, A. Butterworth, S. J. Pope, D. Pfeiffer, and C. J. Nicol. 2008. Leg disorders in broiler chickens: Prevalence, risk factors and prevention. Plos ONE 3:e1545.

KWIN-V. 2011. Kwantitatieve Informatie Veehouderij 2011–2012. Wageningen UR Livestock Research, Lelystad, the Netherlands.

Lasher, H. N., and S. M. Shane. 1994. Infectious bursal disease. World's Poult. Sci. J. 50:133–166. http://dx.doi.org/10.1079/WPS19940013.

Lister, S., and B. Van Nijhuis. 2012. The effects of alternative systems on disease and health of poultry. Pages 62–76 in Alternative Systems for Poultry: Health, Welfare and Productivity. Poultry Science Symposium Series. V. Sandilands and P. M. Hocking, ed. CABI, Wallingford, Oxfordshire, UK; Cambridge, MA.

Lopez, J., R. McFarlane, and T. Scott. 2006. Environmental factors influence the prevalence of infectious bronchitis virus. Proc. Aust. Poult. Sci. Symp. 18:56–59. (Abstr.)

Lovland, A., and M. Kaldhusdal. 2001. Severely impaired production performance in broiler flocks with high incidence of *Clostridium perfringens*-associated hepatitis. Avian Pathol. 30:73–81. http://dx.doi.org/10.1080/03079450020023230.

Lund, V., and B. Algers. 2003. Research on animal health and welfare in organic farming—A literature review. Livest. Prod. Sci. 80:55–68. http://dx.doi.org/10.1016/S0301-6226(02)00321-4.

Manning, L., S. A. Chadd, and R. N. Baines. 2007. Key health and welfare indicators for broiler production. World's Poult. Sci. 63:46–62.

Matthijs, M. G. R., J. H. H. van Eck, W. J. M. Landman, and J. A. Stegeman. 2003. Ability of Massachusetts-type infectious bronchitis virus to increase colibacillosis susceptibility incommercial broilers: A comparison between vaccine and virulent field virus. Avian Pathol. 32:473–481. http://dx.doi.org/10.1080/0307945031000154062.

Maxwell, M. H., and G. W. Robertson. 1998. UK survey of broiler ascites and sudden death syndromes in 1993. Br. Poult. Sci. 39:203–215. http://dx.doi.org/10.1080/00071669889132.

McDevitt, R. M., J. D. Brooker, T. Acamovic, and N. H. C. Sparks. 2006. Necrotic enteritis; a continuing challenge for the poultry industry. World's Poult. Sci. J. 62:221–247. http://dx.doi.org/10.1079/Wps200593.

McIlroy, S. G., E. A. Goodall, D. W. Bruce, R. M. McCracken, and M. S. McNulty. 1992. The cost benefit of vaccinating broiler flocks against subclinical infectious bursal disease on broiler production. Avian Pathol. 21:65–76.

McIlroy, S. G., E. A. Goodall, and R. M. McCracken. 1989. Economic effects of subclinical infectious bursal disease on broiler production. Avian Pathol. 18:465–480. http://dx.doi.org/10.1080/03079458908418619.

McInerney, J. P. 1996. Old economics for new problems—Livestock disease: Presidential address. J. Agric. Econ. 47:295–314.

McInerney, J. P. 2004. Animal welfare, economics and policy. Report on a study undertaken for the Farm & Animal Health Economics Division of Defra. Accessed Nov. 25, 2013. http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/documents/animalwelfare.pdf.

McInerney, J. P., K. S. Howe, and J. A. Schepers. 1992. A framework for the economic-analysis of disease in farm livestock. Prev. Vet. Med. 13:137–154. http://dx.doi.org/10.1016/0167-5877(92)90098-Z.

Müller, H., M. R. Islam, and R. Raue. 2003. Research on infectious bursal disease—The past, the present and the future. Vet. Microbiol. 97:153–165. http://dx.doi.org/10.1016/j.vetmic.2003.08.005.

Müller, H., E. Mundt, N. Eterradossi, and M. R. Islam. 2012. Current status of vaccines against infectious bursal disease. Avian Pathol. 41:133–139. http://dx.doi.org/10.1080/03079457.2012.661403.

Newberry, R. C., E. E. Gardiner, and J. R. Hunt. 1987. Behavior of chickens prior to death from Sudden Death Syndrome. Poult. Sci. 66:1446–1450.

Olkowski, A. A., L. Kumor, and H. L. Classen. 1996. Changing epidemiology of ascites in broiler chickens. Can. J. Anim. Sci. 76:135–140.

Puister, L. 2009. Diergezondheidskosten op vleekuikenbedrijven. Accessed Nov. 22, 2013. http://edepot.wur.nl/14723. Wageningen UR, LEI.

PVE. 2011. Antibiotica aanpak pluimveesector. Beleid, cijfers, registratie en benchmarking. Accessed Jan. 31, 2013. http://www.wpsa.nl/pages/pdf/WPSA.08.12.11%20Studiedag%20Erik%20de%20Jonge.pdf.

Rahman, M. A., M. A. Samad, M. B. Rahman, and S. M. L. Kabir. 2004. Bacterio-pathological studies on salmonellosis, colibacillosis and pasteurellosis in natural and experimental infections in chickens. Bangladesh J. Vet. Med. 2:1–8.

Reid, W. M., and J. Johnson. 1970. Pathogenicity of *Eimeria acervulina* in light and heavy coccidial infections. Avian Dis. 14:166–171. http://dx.doi.org/10.2307/1588567.

Ruff, M. D. 1999. Important parasites in poultry production systems. Vet. Parasitol. 84:337–347. http://dx.doi.org/10.1016/S0304-4017(99)00076-X.

Rushton, J. 2009. The Economics of Animal Health and Production. CAB International, Oxfordshire, UK.

Saif, Y. M., A. M. Fadly, J. R. Glisson, L. R. McDougald, L. K. Nolan, and D. E. Swayne. 2003. Diseases of Poultry, 12th ed. Wiley-Blackwell, Ames, IA.

Sanchez, J., H. Stryhn, M. Flensburg, A. K. Ersboll, and I. Dohoo. 2005. Temporal and spatial analysis of the 1999 outbreak of acute clinical infectious bursal disease in broiler flocks in Denmark. Prev. Vet. Med. 71:209–223.

Scheele, C. W., J. D. Van Der Klis, C. Kwakernaak, R. A. Dekker, J. H. Van Middelkoop, J. Buyse, and E. Decuypere. 2005. Ascites and venous carbon dioxide tensions in juvenile chickens of highly selected genotypes and native strains. World's Poult. Sci. J. 61:113–129. http://dx.doi.org/10.1079/WPS200447.

Skinner, J. T., S. Bauer, V. Young, G. Pauling, and J. Wilson. 2010. An economic analysis of the effect of subclinical (mild) necrotic enteritis in broiler chickens. Avian Dis. 54:1237–1240. http://dx.doi.org/10.1637/9399-052110-Reg.1.

Steenhuisen, W., and C. M. C. Vossen. 2001. Kuikens tegen coccidiose: Effectief, maar wel duurder. Pluimveehouderij 31:10–11.

Su, G., P. Sorensen, and S. Kestin. 1999. Meal feeding is more effective than early feed restriction at reducing the prevalence of leg weakness in broiler chickens. Poult. Sci. 78:949–955.

Sullivan, T. W. 1994. Skeletal problems in poultry: Estimated annual cost and descriptions. Poult. Sci. 73:879–882. http://dx.doi.org/10.3382/ps.0730879.

Tian, S., and V. E. Baracos. 1989. Effect of Escherichia coli infection on growth and protein metabolism in broiler chicks (*Gallus domesticus*). Comp. Biochem. Physiol. 94a:323–331.

Van Horne, P. L. M. 2009. Productiekosten van kuikenvlees: Een internationale vergelijking. Rapport 2009–004. Wageningen UR, LEI, The Hague, the Netherlands. Accessed Nov. 22, 2013. http://edepot.wur.nl/3312.

Van Horne, P. L. M., J. Van Harn, J. H. Van Middelkoop, and G. M. L. Tacken. 2003. Perspectieven voor een alternatieve kuikenvleesketen, Marktkansen voor een langzaam groeiend vleeskuiken. Rapport 2.03.20. Landbouw-Economisch Instituut, Den Haag, the Netherlands. Accessed Jan. 31, 2013. http://edepot.wur.nl/31736.

Van Overbeke, I., L. Duchateau, L. D. Zutter, G. Albers, and R. Ducatelle. 2006. A comparison survey of organic and conventional broiler chickens for infectious agents affecting health and food safety. Avian Dis. 50:196–200. http://dx.doi.org/10.1637/7448-093005r.1.

Verma, D. S. 2007. Effects of mycotoxins on the bone structure and leg weakness in poultry: Estimation of the economic loss by leg weakness. Accessed Jun. 7, 2013. http://en.engormix.com/MA-mycotoxins/articles/effects-mycotoxins-bone-structure-t454/p0.htm.

Vermeij, I. 2004. Primaire productiekosten biologisch kuikenvlees. Intern Rapport 505. Wageningen UR, Animal Sciences Group, Lelystad, the Netherlands. Accessed Nov. 22, 2013. http://library.wur.nl/biola/bestanden/1762980.pdf.

Vermeij, I., and P. L. M. Van Horne. 2008. Kostprijs biologische vleeskuikens, Rapport 170. Animal Sciences Group Wageningen University, Lelystad, the Netherlands. Accessed Nov. 22, 2013. http://www.biozoektboer.be/upload_pdf/58_1_kostprijs%20biologische%20vleeskuikens2009.pdf.

Vermeulen, A. N., D. C. Schaap, and T. P. M. Schetters. 2001. Control of coccidiosis in chickens by vaccination. Vet. Parasitol. 100:13–20. http://dx.doi.org/10.1016/S0304-4017(01)00479-4

Verspecht, A., F. Vanhonacker, W. Verbeke, J. Zoons, and G. Van Huylenbroeck. 2011. Economic effect of decreasing stocking densities in broiler production in Belgium. Poult. Sci. 90:1844–1851. http://dx.doi.org/10.3382/ps.2010-01277.

Voeten, A. C. 2000. Gezond Pluimvee, Handboek voor de beroepspluimveehouder en sportfokker. 3rd ed. Utigeverij Terra, Warnsveld.

Voeten, A. C., W. W. Braunius, F. W. Orthel, and M. A. J. van Rijen. 1988. Influence of coccidiosis on growth rate and feed conversion in broilers after experimental infections with *Eimeria acervulina* and *Eimeria maxima*. Vet. Q. 10:256–264. http://dx.doi.org/10.1080/01652176.1988.9694182.

Weeks, C. A., T. D. Danbury, H. C. Davies, P. Hunt, and S. C. Kestin. 2000. The behaviour of broiler chickens and its modification by lameness. Appl. Anim. Behav. Sci. 67:111–125. http://dx.doi.org/10.1016/S0168-1591(99)00102-1.

Wheelhouse, R. K., B. I. Groves, C. A. Hammant, C. Van Dijk, and J. Radu. 1985. Effects of Coccidiostats and dietary protein on performance and water consumption in broiler chickens. Poult. Sci. 64:979–985. http://dx.doi.org/10.3382/ps.0640979.

Williams, R. B. 1998. Epidemiological aspects of the use of live anticoccidial vaccines for chickens. Int. J. Parasitol. 28:1089–1098.

Williams, R. B. 1999. A compartmentalized model for the estimation of the cost of coccidiosis to the world's chicken production industry. Int. J. Parasitol. 29:1209–1229.

Williams, R. B., A. C. Bushell, J. M. Répérant, T. G. Doy, J. H. Morgan, M. W. Shirley, P. Yvoré, M. M. Carr, and Y. Frémont. 1996. A survey of *Eimeria* species in commercially-reared chickens in France during 1994. Avian Pathol. 25:113–130. http://dx.doi.org/10.1080/03079459608419125.

Yalçin, S., P. Settar, and O. Dicle. 1998. Influence of dietary protein and sex on walking ability and bone parameters of broilers. Br. Poult. Sci. 39:251–256. http://dx.doi.org/10.1080/00071669889213.

Yohannes, T., A. K. Sharma, V. Sumi, and S. S. Rout. 2012. Clinical manifestation and growth performance of broiler chickens fed with T-2 toxin and co-infected with infectious bronchitis virus. ISABB J. Food Agric. Sci. 2:30–35.