Production performance and nitrogen flow of Shaver White layers housed in enriched or conventional cage systems

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ABSTRACT Despite the large number of studies examining the impact of cage systems on Ca and P nutrition, data are limited on the N balance of hens when housed under different systems. To this end, an experiment was conducted to assess N balance, manure characteristics, and indices of the performance of laying hens housed in 2 distinct caging systems. A total of 4,836 commercial Shaver White hens were housed in either enriched (EC) or conventional (CC) cages (average floor space per bird of 643 and 468 cm^2, respectively) under semi-controlled environmental conditions. Enriched cages provided hens with a curtained nesting area, scratch pad, and perches. Birds in both systems were phase fed similar layer diets for 11 periods (4 wk each). Data, expressed on a hen basis, were analyzed as repeated measures using the mixed model procedure of SAS. Lower feed disappearance ($P < 0.01$; 92.5 vs. 95.0 ± 0.6 g/d, DM basis) and manure output ($P < 0.01$; 79.8 vs. 91.3 ± 1.2 g/d, as-is basis, and 27.0 vs. 28.1 ± 0.2 g/d, DM basis) were observed in birds housed in EC compared with CC, respectively. Manure DM was 34.1 and 31.0 ± 0.3% for EC and CC, respectively. Egg production, feed conversion ratio, BW, egg weight, and egg mass were not significantly different between the 2 systems. Overall egg N output decreased with age for both cage systems and was not significantly different between the systems. Although no difference was observed in the overall manure N excretion (1.94 and 1.96 ± 0.02 g/d for EC and CC, respectively), hens housed in CC had a significantly ($P < 0.05$) higher N balance compared with those in the EC system (85.0 vs. 30.2 ± 13.6 mg/d, respectively), which could potentially be explained by a higher ($P < 0.05$) manure N excretion in the EC at the later stages of production. The current data provide estimates of the efficiency of N utilization in laying hens housed under different housing conditions.

Key words: caging system, manure nitrogen, nitrogen balance, egg production

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INTRODUCTION

The move toward alternative cage designs for laying hens has the potential to lead to differences in hen behaviors, with subsequent effects on nutrient dynamics. Environmental enrichment provides more varied behavior, which can result in a better physical condition (Appleby et al., 2002), more space for exercise (Cooper and Appleby, 1996; Gunnarsson et al., 2000; Olsson et al., 2002), and better leg bone strength as a result of using the perch (Hughes and Appleby, 1989). Several studies have evaluated the effect of housing systems on bone quality (Hughes and Appleby, 1989; Fleming et al., 1994; Tauson, 1998) and eggshell quality (Van Den Brand et al., 2004). As such, the focus has primarily been on Ca and P dynamics. Studies on other nutrients are limited.

Nitrogen is a key element in animal production, being one of the more expensive nutrients in poultry diets. When considering dietary protein, its nutritional value is influenced by several factors, including management and housing type (Ishibashi and Yonemochi, 2003). In addition, approximately 30 to 40% or less of the N consumed is retained for maintenance, growth, and product output while the remainder is excreted (Kebreab et al., 2005; Summers, 2008). Furthermore, N has been the focus of several studies related to manure management because (together with P) it is an environmental concern (Smith et al., 2000; Meluzzi et al., 2001; Nahm, 2007). However, less information is available to compare the effects of environmental enrichment of housing type on the N flow and balance of laying hens. Increased dietary nutrient density (Jackson and Waldroup, 1988) and, more specifically, increased dietary protein (Owings et al., 1967) were found to par-

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tially overcome the effect of reduced cage space on egg production in laying hens. However, Brake and Peebles (1992), using graded levels of dietary lysine (0.68 to 0.78%, increasing by 0.05%), detected no effects of increased dietary lysine on performance when hens were housed under higher densities (i.e., comparing 3, 2, and 1 hen/cage in a 25.4 × 40.0 cm cage space). In general, the available comparative data related to nutrient flow, as affected by housing systems, stems from European experiences (e.g., Groot Koerkamp et al., 1999; De Boer et al., 2000) and may not entirely reflect North American conditions. The strong interest in moving to alternative cage designs in North America necessitates the establishment of data to compare nutrient flow and bird performance under conventional and enriched housing systems to take into account differences attributable to such factors as climate, layer strains, and feed ingredient usage. Therefore, the objective of this study was to assess N flow in Shaver White laying hens when housed in either enriched (**EC**) or conventional (**CC**) caging systems, over a full production cycle.

MATERIALS AND METHODS

For this study, 4,836 beak-treated Shaver White pullets (obtained from Manitoba Perfect Pullets Ltd., Rosenort, Manitoba, Canada) at 19 wk of age were introduced into a caging facility at the poultry unit of the University of Manitoba. Birds were maintained under semicontrolled environmental conditions for 11 periods (28 d each) in an intensive egg production system. Handling and care of hens was in accordance with ethical principles of the Guide to the Care and Use of Experimental Animals (Canadian Council on Animal Care, 1993) and the Recommended Code of Practice for the Care and Handling of Pullets, Layers and Spent Fowl (Canadian Agri-Food Research Council, 2003). All protocols were approved by the University of Manitoba Animal Care Protocol Management and Review Committee.

Cage Design and Description

The cage designs used in this study have been described in detail by Tactacan et al. (2009). The EC (also referred to as furnished cages) housed 24 laying hens. The average floor space area per bird was 642 cm^2. Conventional cages (also referred to as traditional cages) housed 6 laying hens. The average floor space area per bird was 468 cm^2.

Experimental Cage Units and Barn Environment

For each cage system, 10 experimental (test) cage units were randomly selected throughout the barn (middle of the house as well as extreme ends of the house). Each experimental unit consisted of 24 birds (1 EC; 4 grouped CC), for a total of 480 Shaver White laying hens on test. All test cages were located on the bottom tier. Barn temperatures and humidity were controlled by air movement regulated through ventilation provided by inlet and exhaust fans mounted in the side walls. Incandescent light was provided by 60-W bulbs, which produced a lighting intensity of 54 to 67 lux. As the birds were introduced (19 wk of age), 13.5 h/d of lighting was provided, and from wk 22 to the end of lay, the birds were exposed to a 15-h photoperiod, from 0600 to 2100 h.

Management and Sample Collection

A phase feeding program, as recommended for the strain, was used for this trial, with hens housed under the 2 treatments receiving identical nutritional programs. Layer diets, based on a wheat-soybean mix, were formulated according to the nutritional recommendations and specifications of the ISA-Shaver (2007, updates 2009–2010) Nutrition Management Guide-Commercial; Institut de Sélection Animale, Boxmeer, the Netherlands). The diets included phases I (periods 1 to 6), II (periods 7 to 9), and III (periods 10 and 11), with corresponding N contents of 3.49, 2.93, and 2.86 ± 0.10%, respectively. Because this study was designed to provide baseline nutrient flow data for subsequent nutrient modeling purposes, the diets did not contain added phytase or exogenous enzymes. During the production cycle, a 5-d sample collection period was conducted in the middle of each 4-wk period. Apart from the 5-d collection period, all the birds were fed ad libitum. During the 5-d collection period, both sides of each test cage units were partitioned using rigid dividers, and a known amount of feed was poured manually into the troughs; the final weigh-back was determined on d 5. Feed disappearance, including feed wastage (observed to be minimal), was calculated as the difference between the feed offered and the final weigh-back. To reduce excessive loss or spillage, wire mesh (2.5 × 3.8 cm mesh size) was used to cover the feeding troughs throughout the barn, and the feed was rationed in 2 lots (d 1 and 4). For the test cage units, feed disappearance, as a measure of feed intake, was taken on a 5-d basis and was calculated as the mean for each 24-bird replicate per cage unit as the total feed offered minus the weigh-back divided by the number of birds (24) and days of feeding (5). Feed samples were obtained from each batch delivered to the production unit. Subsamples were ground and sieved through a 1-mm screen and stored for analysis.

Water was provided ad libitum by using nipple drinkers (1 nipple/8 hens and 1 nipple/6 hens for the EC and CC systems, respectively) mounted along the center of each row, shared by both sides of the cage unit, which is in line with the recommended code of practice for White layer adults in Canada (Canadian Agri-Food Research Council, 2003). Water (chlorinated) was supplied from a municipal source. Water meters were placed on lines supplying the EC rows and the CC rows, thus permitting the monitoring of total water consumption by cage type over the entire production unit, but not specifically for the experimental cage units. Water consumption readings were taken every morning at 0800 h. The difference in the reading between the 2 consecutive days divided by the number of hens housed was calculated as the daily consumption per bird.

All hens in the barn were inspected daily, and any dead or killed birds were recorded. Losses from test cages were replaced with spare birds of similar BW from nontest cages. Daily measurements of barn temperature, humidity, and egg production were recorded. Throughout the production cycle, BW for birds in 5 selected test cage units for each system was recorded individually at the beginning of every 5-d collection period.

Manure was removed by a conveyor belt system beneath each cage tier. Manure from test cages was collected separately using plastic trays or sheets placed on the conveyor belts underneath each test cage unit during the 5-d collection period. Sheets with dimensions of 57 cm width × 258 cm length for the EC system and 48 cm width × 202 cm length for the CC system were used. Manure was collected twice during the 5-d period. On the fifth day, total manure output per replicate was pooled, homogenized by using a mixing implement attached to an electric hand drill, and weighed to obtain the total manure weight. Subsamples of 1.5 to 2 kg were obtained and frozen at −20°C before being freeze-dried, ground to pass through a 1-mm sieve screen, and stored for subsequent analysis. Consistent with commercial production practices, the collected manure included excreta, spilled water and feed, feathers, and broken eggs.

Although egg production data were available for the entire production cycle, for the purposes of this study, egg production was calculated for every 5-d collection period. For egg weight measurements and composition, 4 eggs were sampled daily during the 5-d collection period from each cage unit and immediately stored in an egg cooler (10 to 12°C). On d 6, the eggs were removed from the cooler and weighed (total weight of 20 eggs per cage unit) using a digital scale. Mean egg weight per cage unit was obtained by dividing the total egg weight by 20. Hen-day egg production was calculated by dividing the number of eggs produced by the number of live birds in each cage unit during the 5-d collection period. Egg mass output was calculated by multiplying the actual hen-day rate of egg production by the average egg weight in grams. Feed conversion ratios (**FCR**) were calculated by dividing feed (g) by egg mass (g).

Egg Component Assessment

Ten eggs were broken and the yolks were carefully separated from the whites (albumen) with an egg separator. The yolk, white, and shell samples were pooled and homogenized to yield 2 replicates of 5 eggs each for every cage unit, placed in labeled plastic bags, and weighed. The samples were frozen at −20°C and later freeze-dried and weighed. Corresponding final freeze-dried weights were taken for the different component samples to determine the DM of the samples. Samples were then ground and sieved through a 1-mm screen and stored for further analysis.

Chemical Analysis

Feed, manure, and egg component weights, on both a fresh and DM basis, were recorded. Nitrogen content was determined using a CNS-2000 C, N, and S analyzer (Leco, St. Joseph, MI). To obtain the total egg N output, the individual egg component N outputs were summed. Nitrogen balance or retention indices were calculated, taking into account the amounts of N ingested, the amount retained in the egg components, and the N excreted in manure.

Statistical Analysis

Data were analyzed as repeated measures using the mixed-model procedure of SAS (SAS 9.2, SAS Institute Inc., Cary, NC). The model consisted of a randomized complete block design (factorial), modified into a split plot, with cages (treatment) as the error term for the main effect attributable to the treatment (type of cage system). The cage location within the barn served as the blocking criterion, and this was the random effect (used as a covariable). In the subplot, experimental period and treatment × period interactions were considered fixed effects, and the residuals were used as the error term. The univariate linear model used in the analysis is summarized below:

$$Y_{ijk} = \mu + t_i + t(\text{cage})_j + tp_{ij} + p_k + e_{ijk},$$

where Y_{ijk} is the observation of the parameter tested; μ is the model constant; t_i is the effect of caging system, which is the treatment (i = 1, 2); $t(\text{cage})_j$ is the effect of the different locations of cage units within a cage system (j = 1 to 10); p_k is the effect of the experimental period (k = 1 to 11); tp_{ij} is the interaction between cage system and experimental period (treatment × period); and e_{ijk} is the random error variation.

Least squares means were estimated for all the parameters investigated. No difference in the outcomes was observed among the different variance-covariance structures; hence, for all the analyses, the compound symmetry of the variance-covariance structure was used. Differences between means were determined using the least squares differences by Tukey's test. The significance level was declared at $P \leq 0.05$ in all comparisons unless otherwise stated. The influence of water intake, temperature, and humidity on feed intake and on manure weight was assessed using the REG procedure of SAS (SAS 9.2, SAS Institute) for determining the covariance. A univariate diagnostic analysis allowing for studentized residuals was conducted to check for outliers.

RESULTS

Bird Performance Parameters

In all the parameters, period (bird maturity) had a significant ($P < 0.0001$) influence on the performance of laying hens. Feed disappearance was significantly ($P < 0.01$) higher in birds housed in the CC system compared with the EC system (overall means of 95.0 and 92.5 g/hen per day, respectively). However, in the early stages (i.e., 19 to 27 wk of bird age), no marked differences were observed in feed disappearance between the 2 systems (Figure 1a). The results also showed that after period 2, the feed disappearance of hens within a cage system did not fluctuate during the entire laying period. Although the overall egg production (percentage, hen-day basis), FCR, egg quality parameters (egg weight and egg mass), and BW were numerically higher in birds housed in the CC system, no statistical difference was observed between the 2 systems (Table 1). However, there was a significant cage type × period interaction of BW ($P < 0.01$) and egg weight ($P < 0.001$). The results indicated that BW for birds in the CC system (1.63 ± 0.01 kg/hen) were significantly ($P < 0.01$) more than those in the EC system (1.58 ± 0.01 kg/hen) in period 3 (Figure 1b). In addition, birds in the CC system produced significantly heavier eggs ($P < 0.05$) than those in the EC system in period 5 (61.3 vs. 59.7 ± 0.34 g, respectively) and period 6 (61.8 vs. 60.7 ± 0.34 g, respectively; Figure 1c).

Manure Assessment

The difference in overall mean manure weight between the 2 systems (on an as-is basis) was significant ($P < 0.0001$), with CC birds excreting 91.3 g/d per hen, 11.5 g/d more than the EC birds. Manure DM from hens in EC (34.1%) was significantly ($P < 0.01$) higher than that from hens in CC (31.0%), resulting in a significant ($P < 0.01$) difference in the DM-based manure weight (27.0 and 28.1 g/hen per day for EC and CC birds, respectively) shown in Table 2. These results were slightly lower than the values of manure output predicted by Smith et al. (2000) when using caged birds under intensive production (34.4 g/d on a DM basis or 115 g/d of fresh excreta per hen at 30% of DM).

Overall manure N losses from the 2 cage systems were not significantly different. Energy loss in manure was lower ($P < 0.01$) for EC birds than for their counterparts in CC. Although the assessment of manure output (Table 3) showed higher manure N for birds in CC than those in EC between periods 1 and 8, a significant ($P < 0.01$) effect of a housing type × period interaction on manure N content was observed in period 3 and then later in period 8 (EC = 2.09 and 1.85; CC = 2.24 and 2.02 ± 0.04, respectively). In the later stages of production (periods 9 to 11), birds in EC excreted more ($P < 0.05$) N in manure than birds in CC.

N Intake, N Output and Deposition in Egg, and N Balance (Retention)

A significantly ($P < 0.05$) higher N intake (Table 4), corresponding to higher feed disappearance, was observed for hens in CC compared with those in EC (3.05 and 2.97 ± 0.02 g/hen per day, respectively). Although overall feed disappearance remained constant after the substantial increase noted between periods 1 and 2 (Figure 1a), overall N intake declined with age of the birds after period 2 (Figure 2a). Despite the decrease in N content of the diet from one phase to the next, an increase in N intake was observed in period 9, with declines thereafter.

Results from individual egg analyses showed no significant differences in the N output in egg whites (558 and 564 ± 4.26 mg/hen per day, respectively); however, the deposited N in egg white was significantly ($P < 0.01$) influenced by the interaction effect of cage × period. Egg white N was higher for the birds in CC (650 vs. 608 ± 7.03 mg/hen per day for birds in CC and EC, respectively) in period 4, a period of maximum egg production. Similarly, it was evident that during periods 4 to 6, egg weights were significantly higher ($P < 0.05$) for hens in CC compared with those in EC (Figure 1c). In both cage systems, N output in egg whites declined after peak egg production. Similarly, the overall mean N output in egg yolks was significantly ($P < 0.05$) higher for birds in CC compared with those in EC. Overall N content in egg yolks was maintained at relatively constant levels over the periods following the initial increase between periods 1 and 2. The trends in the N content of egg yolks and egg whites may be related to the duration of accumulation or formation of egg components, in which egg white deposition takes place over a short period, approximately 6 h (Downing and Bryden, 2002), unlike the egg yolk, which accumulates over a longer period of 7 to 12 d (Johnson, 1986). The N output in eggshells (53.3 and 54.6 ± 0.91 mg/hen per day respectively) for birds in EC and CC was not significantly different (Table 4).

The N outputs in individual egg components were summed to obtain the whole-egg N output (Table 4 and Figure 3). No significant difference was observed in egg N outputs between the 2 cage systems. Overall, hens in CC had a significantly ($P < 0.05$) higher N balance than birds in EC, retaining 2.60 ± 0.46% of N intake compared with 0.65 ± 0.46% for birds in EC (Figure 2b and Table 4).

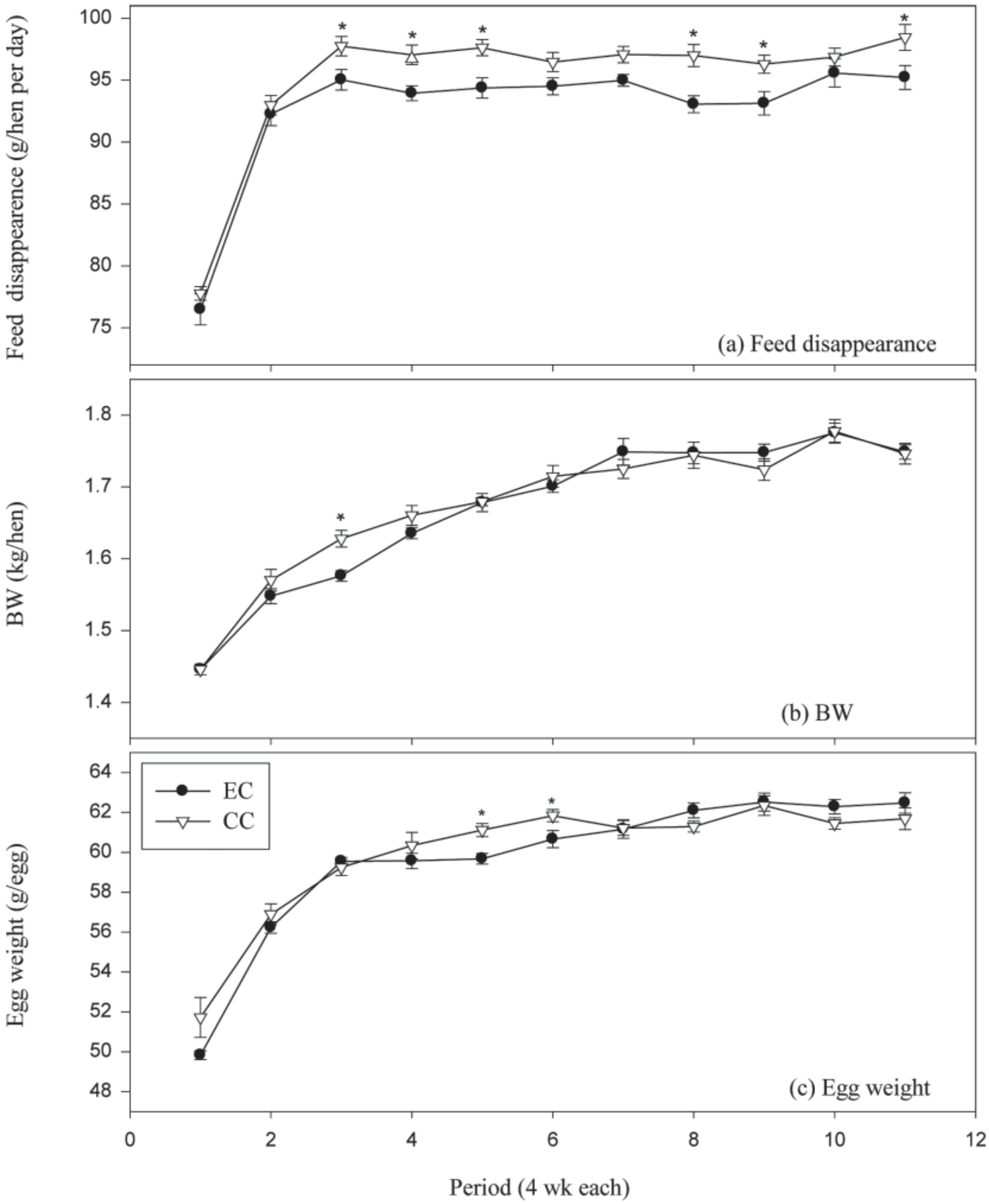

Figure 1. Feed disappearance, BW, and egg weight measurements of laying hens reared in either enriched (EC) or conventional (CC) cages over an entire production cycle (*$P < 0.05$).

DISCUSSION

In this study, higher feed disappearance ($P < 0.01$), manure output ($P < 0.01$), and N balance ($P < 0.05$) were found in hens housed in CC systems compared with those in EC systems. Studies comparing feed intake by hens housed in caged systems report contradictory findings. Previous studies (e.g., Preisinger, 2000; Pohle and Cheng, 2009) have indicated higher levels of feeding behavior in birds housed in furnished than in conventional systems. Similarly, Appleby and Hughes (1991) reported reduced feed consumption as a result of raising layers at high stocking densities. The authors attributed the higher feed intake at a lower stocking density in EC to the requirement for more feed to provide energy for heat production to compensate for the lower heat generated by cage mates. However, in the current study, on a daily average basis, feed disappearance was 2.5 g/hen greater ($P < 0.01$) in the CC system than in the EC system.

In line with the current result on feed disappearance, earlier studies (Glatz and Barnett, 1996) found lower feed intakes in hens housed in cages equipped with perches (as in EC) than in cages without a perch (as in CC). Similarly, bird activity tends to increase with increasing group size when associated with the cage

Table 1. Feed intake and performance of Shaver White hens under conventional (CC) and enriched cage (EC) systems[1]

Item	Feed disappearance (g/hen per day)	BW (kg/hen)	Egg production (%)	Egg wt (g)	Egg mass (g/hen per day)	Feed conversion ratio (g of feed/g of egg)
Cage system[2]						
EC	92.5	1.67	90.6	59.7	54.3	1.76
CC	95.0	1.67	91.7	59.8	55.2	1.78
SE	0.61	0.01	0.43	0.24	0.37	0.01
Period[3]						
1	77.1^{c}	1.45^{h}	55.4^{d}	50.3^{h}	27.9^{e}	2.83^{a}
2	92.6^{b}	1.56^{g}	97.0^{a}	56.3^{g}	54.6^{d}	1.70^{b}
3	96.4^{a}	1.60^{f}	97.7^{a}	59.2^{f}	57.9^{abc}	1.67^{b}
4	95.5^{a}	1.65^{e}	97.9^{a}	59.7^{ef}	58.4^{abc}	1.64^{b}
5	96.0^{a}	1.68^{de}	97.4^{a}	60.4^{de}	58.8^{ab}	1.63^{b}
6	95.5^{a}	1.71^{cd}	96.5^{a}	61.3^{bd}	59.1^{a}	1.62^{b}
7	95.5^{a}	1.74^{bc}	94.2^{ab}	61.1^{cd}	57.6^{a}	1.66^{b}
8	95.0^{a}	1.75^{ab}	94.5^{ab}	61.7^{abc}	58.3^{ab}	1.63^{b}
9	94.7^{a}	1.74^{bc}	92.3^{bc}	62.6^{a}	57.7^{a}	1.64^{b}
10	96.2^{a}	1.78^{a}	90.2^{c}	62.0^{abc}	55.9^{cd}	1.72^{b}
11	96.8^{a}	1.75^{ab}	89.4^{c}	62.1^{ab}	56.3^{bcd}	1.73^{b}
SE	0.61	0.01	0.86	0.27	0.59	0.03
P-value						
Cage	<0.01	NS	NS	NS	NS	NS
Period	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cage × period[4]	NS	<0.01	NS	<0.001	NS	NS

[a–h]Means within each column with different superscripts are significantly different at $P < 0.05$.

[1]Data are presented as least squares means and their SE.

[2]Least squares means as a main effect of cage type.

[3]Least squares means as a main effect of period on the overall mean of CC and EC systems.

[4]Cage × period indicates an interaction of caging system and period for all the parameters tested over an entire production cycle.

area (Carey et al., 1995; Albentosa et al., 2007), which can be explained by the synchronous feeding of hens (Hughes, 1971). In addition, Matsui et al. (2004) and Elson and Croxall (2006) reported a lower feed intake for birds in furnished compared with conventional cages. Furnishing cages with perches tend to decrease bird

Table 2. Manure volume, N, and energy assessment during an entire production cycle of Shaver White hens under conventional (CC) and enriched cage (EC) systems[1]

Item	DM (%)	Manure wt (as-is basis, g/hen per day)	Manure wt (DM basis, g/hen per day)	Manure N (g/hen per day)	Manure gross energy content (MJ/hen per day)
Cage system[2]					
EC	34.1	79.8	27.0	1.94	0.35
CC	31.0	91.3	28.1	1.96	0.36
SE	0.32	1.18	0.23	0.02	0.003
Period[3]					
1	35.4^{a}	71.7^{e}	25.1^{d}	1.85^{ef}	0.31^{d}
2	31.0^{de}	91.8^{a}	28.3^{a}	2.22^{a}	0.38^{a}
3	31.5^{cde}	92.8^{a}	29.0^{a}	2.17^{ab}	0.38^{a}
4	30.5^{e}	93.6^{a}	28.4^{a}	2.15^{abc}	0.38^{a}
5	31.5^{cde}	90.9^{ab}	28.4^{a}	2.09^{bc}	0.37^{ab}
6	31.4^{cde}	90.7^{ab}	28.3^{a}	2.04^{cd}	0.35^{bc}
7	34.1^{ab}	82.8^{cd}	28.2^{ab}	1.84^{ef}	0.35^{bc}
8	32.8^{bcd}	86.5^{bc}	28.2^{ab}	1.93^{de}	0.35^{bc}
9	33.0^{bcd}	81.4^{d}	26.7^{c}	1.71^{g}	0.33^{cd}
10	33.1^{bc}	78.9^{d}	26.0^{cd}	1.77^{fg}	0.35^{bc}
11	33.8^{ab}	80.6^{d}	27.0^{bc}	1.68^{g}	0.37^{ab}
SE	0.47	1.31	0.31	0.03	0.005
P-value					
Cage	<0.0001	<0.0001	<0.01	NS	<0.01
Period	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cage × period[4]	NS	NS	NS	<0.0001	NS

[a–g]Means within each column with different superscripts are significantly different at $P < 0.05$.

[1]Data are presented as least squares means and their SE.

[2]Least squares means as a main effect of cage type.

[3]Least squares means as a main effect of period on the overall mean of CC and EC systems.

[4]Cage × period indicates an interaction of caging system and period for all the parameters tested over an entire production cycle.

Table 3. Nitrogen excretion in manure as a function of a cage type × period effect (hen basis), and significant differences between the conventional (CC) and enriched cage (EC) systems

	Manure N[1] (g/hen per day) ± 0.04		
Period	EC	CC	*P*-value
1	1.83	1.87	NS
2	2.18	2.25	NS
3	2.09	2.24	**
4	2.14	2.17	NS
5	2.06	2.11	NS
6	2.04	2.04	NS
7	1.82	1.85	NS
8	1.85	2.02	**
9	1.80	1.63	**
10	1.83	1.71	*
11	1.74	1.63	*

[1]Least squares means and SE (±0.04).

$^{*}P \le 0.05$; $^{**}P \le 0.01$.

activity (Matsui et al., 2004), increase the amount of resting behavior occurring in the cage (Tauson, 1998), and provide better insulation of the hens' bodies at night when roosting on the perch (Lill, 1968).

Other explanations besides feed consumption may account for differences in feed disappearance between the 2 cage systems, including feeder space and design. Approximately 128 and 104 cm^2/hen of feeder space was provided by the EC and CC systems, respectively. The smaller feeding space in the CC system may have led to competition and aggressive feeding behavior, which may have contributed to potential differences in feed. Thogerson et al. (2009), who reported the effect of feeder space on the behavior of caged Hy-Line W-36 hens, showed that hens with less feeder space used more feed in a short time, suggesting a possible indicator of increased feed wastage. It is also possible that the barren environment in CC systems leads to redundancy, and as a consequence, the birds in CC spend more time eating. These contradictions in feeding behavior between the 2 systems may be partly due to differences in the strains of birds used and the differences in cage floor space per bird (Adams and Jackson, 1970). Feed disappearance could also be influenced by water intake. In this study, a significant ($P < 0.05$, $R^2 = 26.2\%$) but weak correlation was found between water and feed disappearance (both provided ad libitum).

All performance parameters were highly influenced by bird maturity (period effects). The 2 cage systems did not differ in their performance characteristics (egg production, egg weight, egg mass, BW, FCR). The overall mean egg production was not significantly different ($P = 0.0748$) between the 2 cage systems. These results agree with those of Tactacan et al. (2009), who showed no marked differences in egg production between CC and EC systems used for Shaver White hens. Although under a similar setting, the authors used 5 hens in the CC, compared with 6 hens used in the current study, and they found no significant difference in production performance between the 2 housing systems. This agrees with the report that available floor space has

Table 4. Nitrogen flow over the entire production cycle in Shaver White hens placed in either enriched (EC) or conventional (CC) cages[1]

			N deposition (mg/hen per day)			N retention	
Item	N intake (g/hen per day)	Whole-egg N (output, mg/g of egg)	Eggshell	Egg white	Egg yolk	Absolute (mg/hen per day)	Percentage of intake
Cage system[2]							
EC	2.97	18.4	53.3	558	388	30.2	0.65
CC	3.05	18.4	54.6	564	393	85.0	2.60
SE	0.02	0.04	0.91	4.26	1.73	13.6	0.46
Period[3]							
1	2.85[e]	19.0[b]	34.9[e]	331[e]	166[g]	464[a]	16.2[a]
2	3.46[a]	19.6[a]	66.4[a]	639[ab]	367[f]	166[bc]	4.79[bc]
3	3.41[a]	18.9[bc]	57.7[b]	647[a]	390[e]	159[bc]	4.65[bcd]
4	3.23[b]	18.9[bc]	53.4[bc]	629[ab]	418[bcd]	−28.0[de]	−0.92[ef]
5	3.23[b]	18.9[bc]	53.1[bc]	623[b]	436[a]	27.6[de]	0.84[def]
6	3.09[c]	18.6[c]	47.9[d]	632[ab]	426[ab]	−53.4[e]	−1.73[f]
7	2.82[e]	17.8[de]	52.8[bc]	551[c]	422[bc]	−43.7[e]	−1.61[f]
8	2.55[g]	17.6[ef]	53.8[b]	548[c]	426[ab]	−414[f]	−16.3[g]
9	2.98[d]	17.6[ef]	53.5[bc]	548[c]	413[cd]	259[b]	8.57[b]
10	2.82[e]	17.4[f]	50.7[cd]	511[d]	409[d]	78.8[cd]	2.74[cde]
11	2.70[f]	18.0[d]	69.7[a]	511[d]	422[bc]	18.9[de]	0.60[ef]
SE	0.02	0.08	1.18	4.97	2.68	26.5	0.86
P-value							
Cage	<0.05	NS	NS	NS	<0.05	<0.05	<0.01
Period	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cage × period[4]	NS	NS	NS	<0.01	<0.001	<0.001	<0.001

[a–g]Means within each column with different superscripts are significantly different at $P < 0.05$.

[1]Data are presented as least squares means and their SE.

[2]Least squares means as a main effect of cage type.

[3]Least squares means as a main effect of period on the overall mean of CC and EC systems.

[4]Cage × period indicates an interaction of caging system and period for all the parameters tested over an entire production cycle.

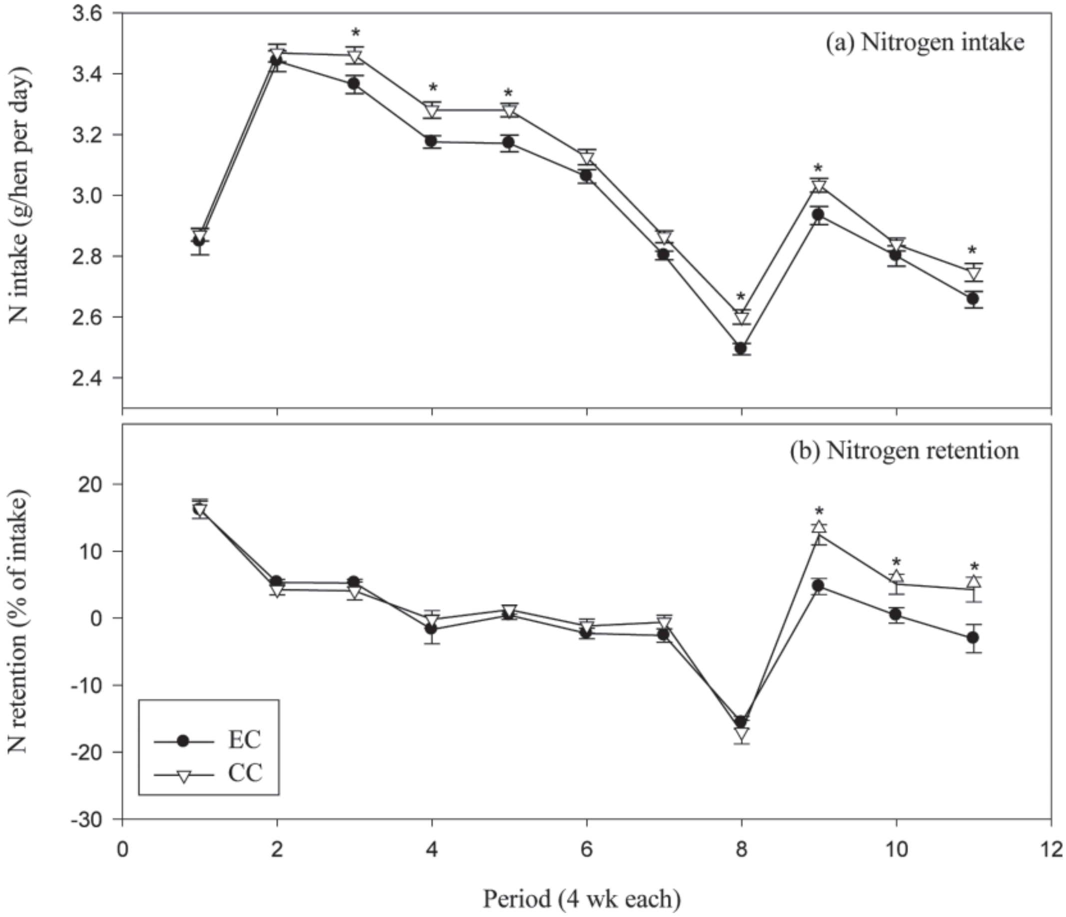

Figure 2. Nitrogen intake and percentage of retention over an entire production cycle in Shaver White hens placed in either enriched (EC) or conventional (CC) cages (*$P < 0.05$).

more influence on laying performance than the number of birds per cage (Marr and Green, 1970). Similarly, results by Benyi et al. (2006) showed significant interactions between strain (Hy-Line Brown hens) and floor space for egg production, egg weight, egg output, and mortality, and they suggested a floor space of 733 cm^2/hen for Hy-Line Brown hens reared in semiarid areas. Specific results on the effect of stocking density on egg production (Johnson et al., 1974; Gonzalez et al., 1978; Benyi et al., 2006) showed no marked differ-

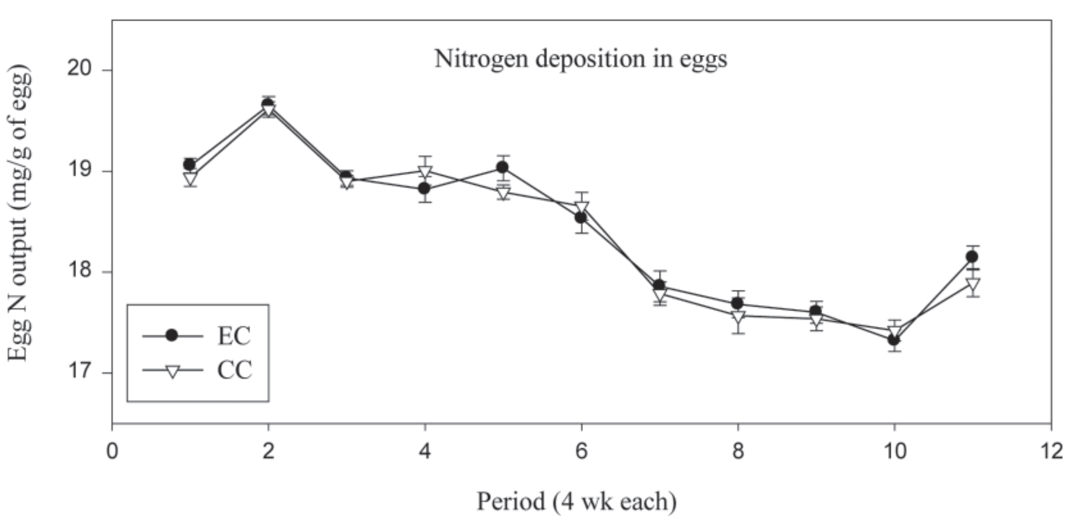

Figure 3. Nitrogen output in whole eggs (DM basis) from Shaver White laying hens in enriched (EC) or conventional (CC) cage systems over an entire production cycle.

ence. Studies by Abrahamsson et al. (1995), although based on strain differences, showed higher egg production for a white strain than for a brown strain reared in CC. These results supports the claim that the density of hens within the limits tested (considering hen strain and environmental conditions) did not significantly influence production.

Higher feed disappearance with birds in CC was likely a factor affecting the cage × period interaction, which showed a significantly ($P < 0.01$) higher BW in period 3. After period 3, no marked difference in BW was found within the CC and between the 2 systems; however, it is possible that several other factors, such as limitations attributable to dietary energy, could influence BW. Guru et al. (1974), working on 2 distinct floor spaces provided by small (930 cm^2) or large (3700 cm^2) cages, noted that egg weight was unaffected by confinement. Similarly, Guesdon and Faure (2004) found no effect of cage system on egg weight. Although there was no main effect of cage system on egg weight in this study, there was a cage type × period interaction for egg weight. A significant ($P < 0.05$) increase in egg weight in the CC system (Figure 1c) was noted following peak egg production (period 5 and 6), probably indicating peak egg mass reserves. In the present study, feed conversion was not significantly different between the 2 cage systems (EC = 1.76 vs. CC = 1.78 ± 0.01 g of feed/g of egg). Although feed conversion can be influenced by the housing system (Vits et al., 2005), in general, caged birds perform better than those in aviary and free-range systems (Hughes et al., 1985).

Manure output from hens housed in the EC and CC systems were 27.0 and 28.1 ± 0.23 g/d per hen on a DM basis and 79.8 vs. 91.3 ± 1.18 g/d per hen at 34 and 31 ± 0.32% of DM, respectively. As indicated earlier, period (age of hen) had a highly significant ($P < 0.0001$) effect on all parameters, including feed disappearance and manure output. Although this was not true with data estimates collected by Smith et al. (2000) from previous experiments, in which the authors found no effect of bird maturity on feed intake or manure output, the authors noted that the latter 2 parameters were linearly related. This linear relationship between feed intake and manure output agrees with the results in the current study. Lower feed disappearance (92.5 vs. 95.0 ± 0.61 g/hen per day for EC and CC birds, respectively) resulted in a corresponding reduction in fresh manure weight ($P < 0.0001$: EC = 79.8 vs. CC = 91.3 ± 1.18; DM basis ($P < 0.01$): EC = 27.0 vs. CC = 28.1 ± 0.23 g/hen per day). Because no significant difference was found in bird production performance, the correlation may imply better efficiency of feed utilization by birds in EC with the lower feed disappearance.

Similarly, in a study using commercial Leghorn hens in deep-pit housing, Patterson (1994) observed a manure output of 12.5 t/1,000 birds per year (equivalent to 34.2 g/d per hen). This value was slightly higher than those obtained in the current study. The author noted a significant relationship between feed intake and manure output, with 0.33 kg of manure generated per kilogram of feed intake. In our study, corresponding values on a DM basis were 0.29 and 0.30 kg of manure/kg of feed disappearance in the EC and CC systems, respectively. The results may indicate a better feed efficiency with Shaver White hens placed in either cage system compared with Leghorns housed in a deep-pit system, but it is not clear whether these differences are due to dietary or strain influences. The amount of manure DM was inversely related to ration digestibility (Powers and Van Horn, 2001). Similarly, in our study, manure weights (based on fresh and DM) were influenced ($P < 0.001$) by water intake ($R^2 = 54.0$ and 54.5%, respectively). Moisture levels in poultry waste can vary greatly depending on several factors, such as variations in diet, age of the bird, digestive health, and management practices (Patterson and Lorenz, 1997). Hence, manure-feed comparisons may require considerations based on ration specifications and environmental factors. In the current study, the percentage of moisture content of the manure from the CC hens was higher than the manure moisture percentage of hens in EC. The latter observation is likely due to the density of birds and the pattern of excretion on the manure belts, where less opportunity exists for moisture removal from the manure obtained from the hens in CC because of the more compact excretion pattern. Consequently, this will have an impact on manure management aspects such as weight on the manure belt (maintenance cost), transportation, size of manure storage, and disposal.

Patterson (1994) estimated a total N output of 243 kg/1,000 birds per year (equivalent to 0.68 g/d per hen) for commercial Leghorn hens in a deep-pit housing system. Nicholson et al. (1996) predicted (by extrapolation) a manure N loss of 18.0 kg/ton at 30% of DM. This is approximately equivalent to 1.80 g/d per hen, assuming a manure output of 100 g/d per hen with a manure output of 30% of DM (estimate based on results from the present study). Several factors could result in differences in manure N outputs, such as feed N contents that have a direct relationship to manure N output (Meluzzi et al., 2001). In this study, no significant difference was observed in the overall manure N excretion by birds in both cage systems (1.94 and 1.96 ± 0.02 g/d per hen for EC and CC, respectively). However, a significant ($P < 0.05$) cage × period interaction of manure N was noted in our study. Birds in EC excreted lower N in manure for the first two-thirds of the production cycle and excreted higher ($P < 0.05$) manure N in the last stage of the cycle, whereas the excretion patterns were reversed for birds in CC (Table 3). The N content in an average egg was similar (18.4 ± 0.04 mg/g of egg) in birds housed in both systems. On average, this was equivalent to 1 g of N/59 g of egg. This was in agreement with estimates of 6 g of protein/egg indicated by Leveille et al. (1960). Hence, in addition to maintaining egg number and N content, birds housed in EC may possess attributes similar to those based on the modern selection criterion (Whitehead and Fleming, 2000), which aims at producing birds that consume less feed and that attain a low BW to maintain egg production.

Because feed disappearance (after period 2) was not significantly different between periods within each cage system, the N intake relates to the N content in the phase-fed diet (analyzed to be 3.49, 2.93, and 2.86 ± 0.10% for phases I, II, and III, respectively). The decline in N intake was inevitable because of a decrease in the rate of egg production after peak production (Shapiro, 1968), yet after this period, the amino acid requirements for maintenance do not increase (Ishibashi and Yonemochi, 2003). Other biological processes, for example, the yolk protein precursor lipovitellin, which is controlled by the pituitary gonadotrophins, is detected in the plasma only in mature pullets and rapidly falls when birds mature (Redshaw and Follett, 1972), reflecting an active reproductive stage and peak nutrient requirements. In addition, the amino acid N composition of the egg white and egg yolk remains the same (Leeson and Summers, 2005); therefore, the requirement for the nutrient declines as the bird progresses through the laying cycle with advancing age.

Birds housed in CC had a significantly ($P < 0.01$) higher N balance than birds in EC (2.60 vs. 0.65 ± 0.46% intake, respectively). In both cage systems, an overall positive N balance was observed; however, in period 8, birds in both systems were at their lowest N balance (−16.30 ± 0.86% intake). During this period, the hens in both systems were on the second phase of the diet that contained lower N content than in the first phase of the diet. Despite the changing dietary N levels (phase-fed diets), there was a gradual decrease in egg production in this experiment to the end of the laying cycle.

The hen has a protein requirement for more than just egg production, and the continuous changes in N balance (Figure 2b) relate to these demands (e.g., feather growth and protein for BW gain, and may include endogenous protein loss). Nitrogen retention provides a valuable measure of the overall protein nutrition of the laying hen. Although no significant differences were observed in production performance between the 2 systems, a significant difference was found in the N balance between them. In this experiment, N balance was calculated by the input and output relationship (as described by Wu-Haan et al., 2007). Nitrogen intake (inputs) was constituted by the feed, and N outputs consisted of N deposited in the eggs and excreted in manure. Nitrogen intake was greater in hens housed in CC than in EC, given that feed disappearance was significantly ($P < 0.01$) higher in birds housed in CC compared with those housed in the EC system (overall means of feed disappearance was 95.0 and 92.5 g/hen per day, respectively). However, the measured N intake is likely to be higher than the true intake because the higher feed disappearance with hens in CC may not accurately indicate that all the feed was consumed by the hens.

On the other hand, although N intake may be overestimated, N loss (excretion) in manure may also be underestimated. Housing type has a major effect on manure quality (Smith et al., 2000). Because of cage design (space restrictions), individual flock droppings in the CC system heap on conveyor belts and do not spread out, as in the EC system. The thin layer of manure droppings in EC had a more exposed surface area, which would increase the manure drying ability. Manure moisture content for hens in CC (69%) was significantly ($P < 0.01$) higher than that for hens in EC (66%). The lower moisture content in manure corresponds to lower ammonia volatilization and retained N in manure (Yang et al., 2000). Hence, in the current study, the analyzed manure N excretion for EC is likely to be higher than that for the CC system. In addition, manure N levels in the 2 systems may vary depending on the proportions of the different components of poultry manure, such as excreta, feed, feathers, and broken eggs (Nahm, 2005).

In conclusion, although we did not assess N retention per hen per se, but rather N flow within the system, the combination of the analyzed manure N excretion, egg N output, and calculated N retention values may provide valuable estimates of the efficiency of N utilization in laying hens based on a commercial production system. Nitrogen flow in hens housed in EC indicate that they do not perform any less efficiently than those in the CC system. In addition, from the point of view of the producers and the environment, the high manure N excretion in the EC system may suggest a marked potential for linking the role of diet with N flow and managing hens in an EC system especially at a later stage of the laying cycle.

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