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Effects of Elevated Carbon Dioxide Concentrations on Broiler Chicken Performance from 28 to 49 Days†

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Abstract: Improvements in modern broiler housing have substantially reduced air leakage, making proper operation of ventilation systems critical to maintaining a suitable environment. Fuel prices have increased in recent years, leading to reduced minimum ventilation in order to conserve fuel which increases carbon dioxide (CO_2) concentrations within the house. Four trials were conducted to assess the effects of increased CO_2 concentrations on birds aged 28 to 49 days. Each trial used 300 straight-run broilers placed in environmentally controlled rooms where CO_2 concentrations were maintained with no added CO_2 (control), 2500 ppm at all times, 2500 ppm (day) and 4500 ppm (night), or 2500 ppm (day) and 6500 ppm (night) from 28 to 42 days. No differences in live production (body weight, body weight gain, feed intake and feed conversion) or processing yields were observed. Analysis of ventilation rates to maintain the test conditions for a commercial broiler house showed that while supplemental heat requirements are lower with reduced ventilation needed to maintain either 4500 or 6500 ppm, the associated ventilation rates are inadequate for moisture removal.

Key words: Broiler, minimum ventilation, carbon dioxide

INTRODUCTION

Fuel prices have increased and become more volatile in recent years, affecting profitability for contract broiler growers. As a result, contract growers in the U.S. are investing in facility improvements aimed at increasing energy efficiency and reducing fuel usage during brooding.

Air leakage can be a considerable energy loss when brooding (Czarick and Fairchild, 2010), requiring additional energy to maintain the house at the desired temperature. Improved construction practices are being employed to reduce air leakage in new construction and practices such as spray foam insulation are being used in existing structures, resulting in reduced air exchange caused by leakage through the building envelope (Czarick and Fairchild, 2005; Campbell *et al.*, 2009). Coupled with reduced ventilation during cold weather to reduce ventilation heat loss, carbon dioxide (CO_2) concentration within the building may become elevated and negatively impact production and bird health.

Reece and Lott (1980) reported no significant effects of CO_2 exposure on broiler performance over four weeks of exposure (placement to 28 days) for levels of 3,000 and 6,000 ppm; broilers exposed to 12,000 ppm CO_2 showed reduced body weight over the trial, but no effect on feed conversion. Olanrewaju *et al.* (2008) reported CO_2 exposure from placement to 14 days of age did not affect live performance or physiological variables, but did increase late mortality. Both of the preceding studies limited exposure to 28 and 14 days for Reece and Lott (1980) and Olanrewaju *et al.* (2008), respectively. Thus, the production responses of broilers to elevated CO_2 concentrations later in the production cycle are unknown. The objective of this study was to determine the effects of elevated carbon dioxide concentrations which mimic exposure patterns during limited minimum ventilation conditions in cold weather.

MATERIALS AND METHODS

Four trials were performed to assess the effects of elevated CO_2 concentration on broiler performance. All experiments were conducted in a climate-controlled poultry research facility. The facility houses three rooms measuring 3 m x 5.2 m; ventilation is single pass (100% outside air) provided by an air handler continuously supplying 680 $m^3 \cdot h^{-1}$. Temperature is individually controlled in each room by a microprocessor-based valve controller (PD541, Precision Digital Corp., Poccassett, MA) which modulates chilled and hot water coils. Humidity is controlled through steam injection with a separate valve controller (PD540, Precision Digital Corp., Poccassett, MA). In Trial 1, a 3 m x 3 m floor pen was constructed in each room (Fig. 1a); in Trials 2 through 4, each room was subdivided into two smaller rooms measuring 1.5 m x 3 m (Fig. 1b).

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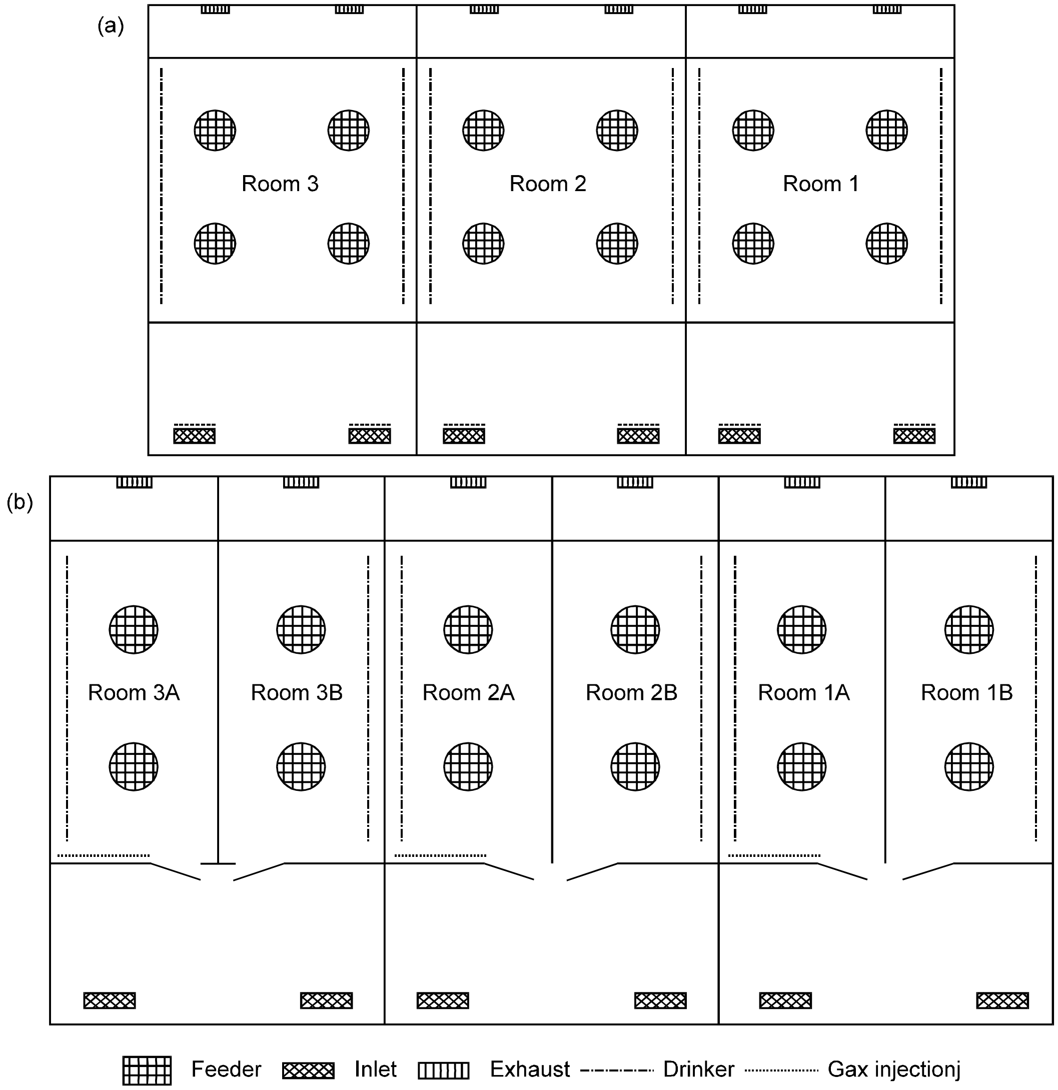

Fig. 1: Plan view of experimental room arrangement for Trial 1 (a) and Trials 2 through 4 (b)

Table 1: Temperature setpoints for placement through 28 days of age

	Air temperature	
Day	°C	°F
Placement	33.3	92
3	32.2	90
6	36.7	88
8	30.6	87
11	30.0	86
14	29.4	85
18	28.9	84
20	28.3	83
22	27.8	82
25	26.7	80

Bird husbandry: Temperature was set to 33.3°C at placement and reduced with bird age according to the schedule in Table 1 until initiation of treatments on day 28; temperature during the treatment period (day 28 to 49) is shown in Table 2. Lighting was provided with 60 W incandescent lamps controlled with a dimmer and digital timer as shown in Table 3. Each room was equipped with a tube feeder and nipple drinker line, with feed and water available *ad libitum*. A four-phase feeding program was used consisting of starter (placement to 14 days), grower (14 to 28 days), finisher (29 to 42 days) and withdrawal (43 to 48 days) diets. Corn-soy diets formulated to mimic those used in commercial practice were used and met or exceeded NRC (1994) recommendations. In Trial 1, 100 birds were placed in each room and 50 birds per room in Trials 2 through 4; stocking density was 10.7 birds/m^2. Litter was recycled from a previous study and top-dressed before each trial began.

Table 2: Temperature and CO_2 treatments applied during treatment period of 28 to 49 d

		Temperature		CO_2 concentration	
Age (day)	Treatment	Day (°C)	Night (°C)	Day (ppm)	Night (ppm)
28 to 34	00CT	25.6	25.6	---------- (-[a]) ---------	
	45CT	25.6	25.6	2500	4500
	65CT	25.6	25.6	2500	6500
	00VT	25.6	22.8	---------- (-[a]) ---------	
	25VT	25.6	22.8	2500	25
35 to 41	00CT	23.9	23.9	---------- (-[a]) ---------	
	45CT	23.9	23.9	2500	4500
	65CT	23.9	23.9	2500	6500
	00VT	23.9	21.1	---------- (-[a]) ---------	
	25VT	23.9	21.1	2500	25
42 to 48	00CT	22.2	22.2	---------- (-[a]) ---------	
	45CT	22.2	22.2	---------- (-[b]) ---------	
	65CT	22.2	22.2	---------- (-[b]) ---------	
	00VT	22.2	19.4	---------- (-[a]) ---------	
	25VT	22.2	19.4	---------- (-[b]) ---------	

[a]No CO_2 was added to these treatments.

[b]CO_2 injection was ended at 42 days of age.

VT = Variable Temperature, CT = Constant Temperature

Table 3: Lighting program used for all treatments

		Intensity	
Age	Duration	Lux	fc
1 to 7	23L:1D	0.19	2.0
8 to 27	18L:6D	0.09	1.0
28 to 47	20L:4D	0.03	0.3
48 to 49	23L:1D	0.03	0.3

Experimental treatments: A series of experimental treatments to mimic housing conditions for differing minimum ventilation conditions was used to determine production responses in a completely randomized design. Four CO_2 concentrations ranging from no addition (control) to 6500 ppm in combination with two temperature regimes, Constant Temperature (CT) and Variable Temperature (VT), were tested and are shown in Table 2. Treatments were applied starting on day 28 and CO_2 addition continued until day 42; temperature regimes continued through day 49. Carbon dioxide and temperature cycles were set on 12 h intervals to approximate increased minimum ventilation duty cycle during the day and reduced minimum ventilation duty cycle at night; cycles were controlled with a ramp and soak controller which allowed for automatic changing of setpoints over time (PD550, Precision Digital Corp., Poccassett, MA). In Trial 1, CO_2 treatments were applied to the entire room; in the remaining trials, paired sub-rooms within a main room were designated as treatment (receiving the CO_2 treatment) or control (no added CO_2) as shown in Fig. 1. This treatment structure resulted in four replications each of the three CO_2 addition treatments, six replications of the constant temperature with no CO_2 addition treatment and three replications of the variable temperature with no CO_2 addition treatment.

Carbon dioxide injection and control: Carbon dioxide concentration was measured in pens with CO_2 injection with a near-infrared sensor (GMT220, Vaisala, Helsinki, Finland) and maintained at setpoint with a valve controller (PD540, Precision Digital Corp., Poccassett, MA); ambient concentrations were spot checked and averaged approximately 400 ppm. The controller employed a Proportional-Integral-Derivative (PID) algorithm to modulate the duty cycle of a solenoid valve (SC8261S406, ASCO, Florham Park, NJ); valve cycle time was set to 1 s. Valve actuation duration increased in response to deviation from setpoint, i.e. as concentration moved further from the setpoint, the valve was opened for longer durations. Gas was supplied from bulk containers connected to a manifold equipped with a pressure regulator set to 207 kPa (30 psi). Solenoid valves were connected to the manifold using nylon tubing (Ø12.7 mm). Gas was injected into the airspace of rooms with a diffuser constructed from plastic pipe (Ø19 mm) with a series of holes (Ø3.2 mm).

Bird performance measurements: Birds and feed were weighed on days 14, 28, 42 and 48 to determine Body Weight (BW), Body Weight Gain (BWG), Feed Intake (FI) and Feed Conversion Ratio (FCR). On day 49, 20 birds in each large room (20 per room in Trial 1 and 10 per sub-room in Trials 2 through 4) were randomly selected for processing to obtain yield data. Feed was removed 12 h before birds were transported to the processing plant. Carcasses and abdominal fat were weighed before splitting carcasses into front and back halves. The front halves were chilled in ice for approximately 4 h before manually deboning to obtain breast fillet and tender weights.

Statistical analysis: Data were analyzed using analysis of variance in PROC MIXED in SAS (v9.2, SAS Institute, Cary, N.C.). Means were separated using Fisher's least significant difference test (Ott, 1993) and significance was considered at $p \le 0.05$. Treatments were replicated over time and as such, trial and treatment x trial interactions were included as covariates in the statistical model.

Ventilation performance analysis: Live performance data recorded during this study were used to estimate CO_2 and moisture production between 14 and 49 days of age to determine minimum ventilation rates and supplemental heat demand for the following cases:

1. Moisture control: Ventilation rates were calculated to maintain a set Relative Humidity (RH) of 60%. Resulting CO_2 concentrations were then calculated.
2. Typical minimum ventilation: Ventilation rates were specified per Donald *et al.* (2002) and resulting CO_2 concentrations were calculated. Ventilation rates used are shown in Table 4.

3. Maintain 2500 ppm CO_2 at 60% RH.
4. Maintain 4500 ppm CO_2 at 60% RH.
5. Maintaining 6500 ppm CO_2 at 60% RH.

Table 4: Minimum ventilation rates for commercial broiler facilities on a per-bird basis from Donald *et al.* (2002)

Week	Q_{min} (m^3•h^{-1})
1	0.17
2	0.42
3	0.59
4	0.85
5	1.10
6	1.19
7	1.36
8	1.53

Total and sensible heat production were estimated per Pedersen and Thomsen (2000), from which CO_2 and moisture production were calculated. Balance equations (Albright, 1990) for sensible heat and CO_2 were solved for cases 1 through 5 for a typical commercial production scenario with the following characteristics:

- House dimensions: 12.2 x 152.4 m (40 x 500 ft) with an average ceiling height of 2.9 m (9.5 ft)
- Stocking density: 10.8 birds/m^2 (1 bird/ft^2)
- Outside temperature: 4.5°C (40°F)
- Outside relative humidity: 50%
- Inside relative humidity: 60%
- Thermal resistance of building envelope:
  - Ceiling: 3.35 m^2•°K•W^{-1} (19 ft^2•°F•h•Btu^{-1})
  - Walls: 1.93 m^2•°K•W^{-1} (11 ft^2•°F•h•Btu^{-1})
- Ambient CO_2 concentration: 400 ppm
- Fuel source: Propane (C_3H_8)
  - Combustion produces (Czarick and Lacy, 2001) 1.53 m^3 CO_2/kg C_3H_8 and 0.16 kg H_2O/kg C_3H_8

RESULTS AND DISCUSSION

The overall means for each of the five temperature and CO_2 addition treatment combinations are shown in Table 5 and 6. No significant differences in live performance were detected between any treatments; broilers in the variable temperature treatments tended to have numerically larger BW, BWG and FI. No significant differences were found in processing and yield data, with the exception of significant differences in breast fillet weight (p = 0.0109). However, breast fillet yield relative to carcass weight was not different. Increased breast fillet weights were observed for the two treatments with the numerically highest BW, BWG and FI. These results

Table 5: Live production characteristics of broilers from 29 to 42 days

Treatment	n	BW (g)	SEM_{BW} (g)	BWG (g)	SEM_{BWG} (g)	FI (g)	SEM_{FI} (g)	FCR (g:g)	SEM_{FCR} (g:g)	Mortality (%)	SEM_{Mort} (%)
00CT	6	2690	31	1317	23	2450	32	1.85	0.02	0.17	0.17
45CT	4	2670	61	1268	32	2380	54	1.88	0.01	0.00	0.00
65CT	4	2677	39	1305	29	2423	46	1.84	0.01	0.50	0.29
00VT	3	2710	22	1326	14	2460	33	1.84	0.02	0.33	0.33
25VT	4	2736	20	1311	47	2481	22	1.84	0.03	1.00	0.71

Table 6: Live production characteristics of broilers from 43 to 48 days

Treatment	n	BW (g)	SEM_{BW} (g)	BWG (g)	SEM_{BWG} (g)	FI (g)	SEM_{FI} (g)	FCR (g:g)	SEM_{FCR} (g:g)	Mortality (%)	SEM_{Mort} (%)
00CT	6	3174	30	463	24	1128	28	2.37	0.05	0.33	0.21
45CT	4	3182	51	512	11	1161	8	2.27	0.04	0.00	0.00
65CT	4	3174	39	495	10	1127	21	2.27	0.02	0.00	0.00
00VT	3	3237	15	526	10	1181	31	2.25	0.02	0.00	0.00
25VT	4	3258	19	514	13	1184	24	2.27	0.03	0.25	0.25

Table 7: Processing and yield characteristics of broilers at 49 d of age subjected to differing carbon dioxide and temperature treatments

		Carcass				Abdominal fat			
Treatment	n	Weight (g)	SEM_{CW} (g)	Yield (%)	SEM_{CY} (%)	Weight (g)	SEM_{AFW} (g)	Yield (%)	SEM_{AFY} (%)
00CT	6	2248	25.5	74.9	1.9	61	3.2	2.1	0.1
45CT	4	2298	31.2	74.9	1.9	63	3.5	2.1	0.1
65CT	4	2281	31.2	75.1	1.9	56	3.5	1.9	0.1
00VT	3	2346	36.0	75.8	1.9	63	4.4	2.1	0.1
25VT	4	2328	31.2	75.1	1.9	61	3.5	2.0	0.1
		Fillet				Tender			
Treatment	n	Weight (g)	SEM_{FW} (g)	Yield (%)	SEM_{FY}	Weight (g)	SEM_{TW} (g)	Yield (%)	SEM_{TY} (%)
00CT	6	561^{c}	11.1	18.7	0.7	125	4.1	4.2	0.1
45CT	4	$588^{a,b}$	11.7	19.2	0.7	129	3.7	4.2	0.1
65CT	4	$574^{b,c}$	11.7	19.9	0.7	125	3.7	4.1	0.1
00VT	3	604^{a}	12.8	19.5	0.7	130	4.3	4.2	0.1
25VT	4	$593^{a,b}$	11.7	19.1	0.7	129	3.7	4.1	0.1

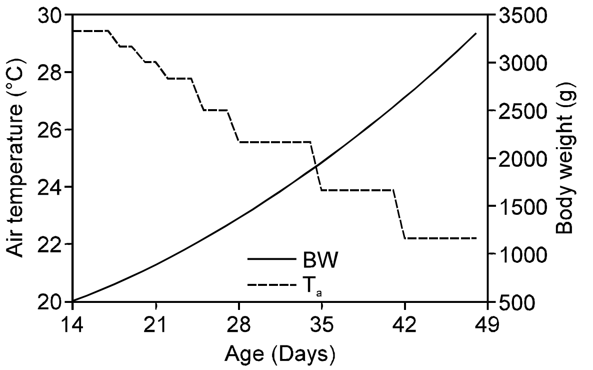

Fig. 2: Mean flock body weight (BW) and air temperature (Ta) setpoints for 14 to 49 days

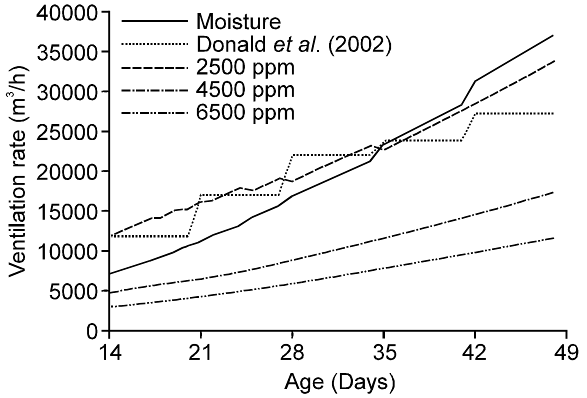

Fig. 3: Comparison of simulated ventilation rates for control of moisture and CO_2 concentrations. Minimum ventilation rates for moisture control or as recommended by Donald *et al.* (2002) are sufficient to control CO_2 concentration below 4500 ppm and 6500 ppm during the 14 to 49 day period

follow those of previous studies with CO_2 exposure during earlier growth periods (Reece and Lott, 1980; Olanrewaju *et al.*, 2008) at comparable concentrations where live performance was not affected by addition of CO_2.

Ventilation performance was simulated for a commercial type facility to determine necessary ventilation rates to maintain the tested concentrations of CO_2 and 60% RH. A time-course plot of body weight and temperature setpoint from 14 to 48 days is shown in Fig. 2; these data were used to calculate heat, moisture and CO_2 production as well as heat loss through the building envelope and ventilation. Ventilation rates for each of the five cases are shown in Fig. 3. Figure 3 illustrates the differences between ventilation rates specified for moisture control versus those for CO_2 concentration control. If ventilating for moisture control either through calculation for moisture balance as described by Albright (1990) or ASAE (2003) or using recommendations by other researchers (Donald *et al.*, 2002), CO_2 concentration within the building should approach 2500 ppm using the production data herein.

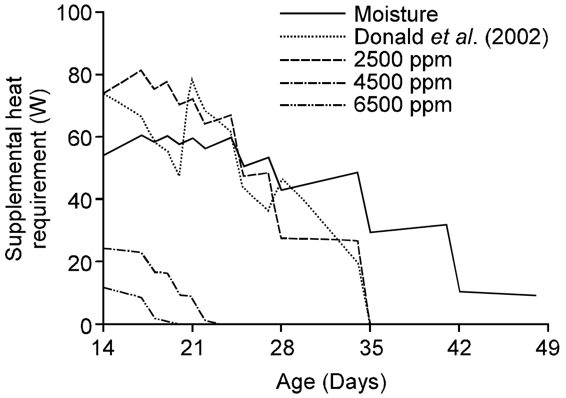

Fig. 4: Simulated supplemental heat demand for days 14 to 49 for each ventilation program. Reduced supplemental heat demand to maintain CO_2 concentrations at 4500 and 6500 ppm is due to insufficient ventilation for moisture control

Supplemental heat requirements to offset heat lost through ventilation are shown in Fig. 4. While fuel use is minimized for ventilation settings which maintain CO_2 concentrations at 4500 or 6500 ppm, the associated ventilation rates are not adequate for proper moisture control. Ventilation rates to control moisture or maintain CO_2 concentration at 2500 ppm remain similar through 28 days of age, but diverge thereafter, due in part to the assumption that by day 35, the ventilation system is primarily operated for temperature control.

While the CO_2 concentrations tested herein did not reduce production efficiency in broiler chickens from 28 to 48 days of age, minimum ventilation rates must be properly applied to maintain suitable litter moisture. Excessive litter moisture may lead to increased ammonia production, necessitating increased minimum ventilation (Xin *et al.*, 1996; Miles *et al.*, 2004) and subsequent increased fuel usage.

Conclusion: Neither live performance nor processing and yield data were influenced by elevated CO_2 exposure from 28 to 42 days in this study. Using the live performance data collected in this study to calculate sensible heat, moisture and CO_2 production from broilers, ventilation rates to maintain the tested CO_2 concentrations were simulated and compared against those for moisture control. Per traditional engineering design guidelines for ventilation systems, ventilation rates to control moisture will usually exceed that required to maintain CO_2 concentration at reasonable levels.

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