Table 4.5 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and tenderloin prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Tenderloin Price	$/kg	3.75	3.31	3.75	4.41
Profitability analysis based on targeted market of selling tenderloin					
Tenderloin Target Weight	kg	0.175	0.175	0.175	0.175
Grower dLys Level	%	1.25	1.25	1.25	1.25
Finisher dLys Level	%	1.05	1.03	1.04	1.06
Feeding Time	Days	49	49	49	49
Targeted Body Weight	kg	4.083	4.082	4.082	4.084
Feed Consume	kg/bird	6.447	6.453	6.452	6.442
Feed per Gain	kg/kg	1.58	1.58	1.58	1.58
Feed Cost	$/bird	2.32	2.31	2.08	2.08
Derived Price[a]	$/kg live bird	1.348	1.328	1.347	1.377
Profit	$/bird	2.191	2.117	2.428	2.538
Birds Initiated[b]	Birds/house	15,905	15,911	15,910	15,900
Broiler House Profit	$/house/period	3,370,476	3,259,013	3,737,155	3,904,009

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.6 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and leg quarters prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Leg Quarters Price	$/kg	0.85	0.80	0.85	0.90
Profitability analysis based on targeted market of selling leg quarters					
Leg Quarters Target Weight	Kg	0.976	0.976	0.975	0.976
Grower dLys Level	%	1.25	1.25	1.25	1.25
Finisher dLys Level	%	1.05	1.04	1.04	1.04
Feeding Time	Days	49	49	49	49
Targeted Body Weight	Kg	4.083	4.083	4.082	4.083
Feed Consume	kg/bird	6.447	6.449	6.452	6.449
Feed per Gain	kg/kg	1.58	1.58	1.58	1.58
Feed Cost	$/bird	2.32	2.32	2.08	2.08
Derived Price[a]	$/kg live bird	1.348	1.337	1.347	1.361
Profit	$/bird	2.191	2.150	2.428	2.479
Birds Initiated[b]	Birds/house	15,905	15,907	15,910	15,907
Broiler House Profit	$/house/period	3,370,476	3,308,042	3,737,155	3,815,062

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.7 Scenarios used to analyze the profitability, dLys levels and feeding days which maximize profit at various feed ingredient and wings prices.

Variable	Unit	Scenarios			
Corn	$/MT	275	275	236	236
SBM	$/MT	400	400	350	350
Wings Price	$/kg	2.39	2.09	2.39	3.97
Profitability analysis based on targeted market of selling wings					
Wings Target Weight	Kg	0.326	0.326	0.326	0.327
Grower dLys Level	%	1.250	1.250	1.250	1.250
Finisher dLys Level	%	1.049	1.033	1.035	1.090
Feeding Time	Days	49	49	49	49
Targeted Body Weight	Kg	4.083	4.082	4.082	4.087
Feed Consume	kg/bird	6.447	6.453	6.452	6.430
Feed per Gain	kg/kg	1.58	1.58	1.58	1.57
Feed Cost	$/bird	2.32	2.31	2.08	2.09
Derived Price[a]	$/kg live bird	1.348	1.313	1.347	1.475
Profit	$/bird	2.191	2.057	2.428	2.918
Birds Initiated[b]	Birds/house	15,905	15,911	15,910	15,888
Broiler House Profit	$/house/period	3,370,476	3,166,787	3,737,155	4,484,138

[a] The price per kg depended on the targeted market times the dock price of each processed part i and subtracted the processing cost, and catching and hauling cost.
[b] Number of birds settle per house at the beginning of grow-out period.

Table 4.8 Composition of the diets during grower and finisher phases which maximize profit for carcass market where corn, SBM and carcass prices were $275 and 400 per MT, and $1.87 per kg, respectively.

Ingredients	Grower Diet	Finisher Diet
Corn	69.47	76.79
Soybean Meal	22.63	16.40
Meat & Bone Meal	3.00	3.00
Poultry Fat	2.19	1.09
L-LysineHCl	0.17	0.16
DL-Methionine	0.27	0.19
L-Threonine	0.07	0.05
Limestone	1.05	1.06
Defluorinated P	0.18	0.23
Salt	0.42	0.27
UGA Vitamin PMX	0.25	0.25
UGA Mineral PMX	0.08	0.08
Choline Chloride	0.05	0.07
S-Carb	0.00	0.19
Copper Sulfate	0.04	0.04
Quantum 2,500	0.02	0.02
BMD-50	0.05	0.05
Coban 90	0.06	0.06
Total	100.00	100.00
Feed cost, $/ MT	367.1	346.8

Table 4.9 Nutrient composition of the diets during grower and finisher phases which maximize profit for the carcass market where corn, SBM and carcass prices were $275 and 400 per MT, and $1.87 per kg, respectively.

Composition	Grower Diet	Finisher Diet
Nutrients (% and Ratios)		
Crude Protein, %	17.45	14.86
ME Mcal / kg	3.16	3.16
Digestible Lys, %	0.89	0.73
Dig Met / Dig Lys	54	52
Dig M+C / Dig Lys	77	77
Dig Thr / Dig Lys	67	67
Dig Trp / Dig Lys	19	19
Dig Ile / Dig Lys	68	68
Dig Val / Dig Lys	79	81
Dig Arg / Dig Lys	116	117
Tot Gly / Dig Lys	93	100
Calcium, %	0.93	0.93
Avaliable P., %	0.46	0.46
Ca / Available P	2.00	2.00
Sodium, %	0.22	0.22
Digestible Amino Acids (%)		
Lysine	0.89	0.73
Methionine	0.48	0.38
Met + Cys	0.68	0.56
Threonine	0.59	0.49
Tryptophan	0.17	0.14
Isoleucine	0.60	0.49
Valine	0.70	0.59
Arginine	1.03	0.85
Leucine	1.27	1.12
Histidine	0.37	0.31
Alanine	0.77	0.68
Glutamic Acid	2.52	2.11
Aspartic Acid	1.36	1.10
Phenylalanine	0.73	0.61
Proline	0.91	0.81
Serine	0.70	0.59
Tyrosine	0.33	0.28
Total Glycine	0.71	0.61
Dig. Essential Amino Acids (DEAA)	6.83	5.69
Dig. Non-essential Amino Acids (DNEAA)	7.50	6.37
Sum of the Dig. AA (DAA)	14.33	12.07
DEAA / DAA	47.65	47.17
DNEAA / DAA	52.35	52.83
DAA / CP	82.15	81.22

Table 4.10 Summary of the scenarios changed to the dLys levels and feeding days which maximize profit at various feed ingredient and cut-up part prices.

Variables (y)	Unit	Profitability analysis based on targeted market of selling cut-up parts				
		Carcass	Breast meat	Tenderloin	Leg quarters	Wings
Cut-Up Part Target Weight	Kg	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Grower dLys Level	%	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$
Finisher dLys Level	%	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Feeding Time	Days	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$	$\frac{\partial y}{\partial P_c} = 0, \frac{\partial y}{\partial P_f} = 0$
Targeted Body Weight	Kg	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Feed Consume	Kg/bird	$\frac{\partial y}{\partial P_c} > or < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > or < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} < 0, \frac{\partial y}{\partial P_f} < 0$
Feed Cost	$/bird	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} > 0$
Profit	$/bird	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$	$\frac{\partial y}{\partial P_c} > 0, \frac{\partial y}{\partial P_f} < 0$

P_c is the price of cut-up part; P_f is the price of feed ingredients.

Table 4.11 Descriptive statistics of the corn and soybean meal (SBM) prices and their spread (SBM minus corn prices) between low volatile period (January 2000 to December 2005) and high volatile period (January 2006 to April 2011).

Descriptive Statistics	Corn $/MT	SBM $/MT	Spread $/MT
Descriptive Statistics between January 2000 and December 2005			
Mean	98.76[b]	204.90[b]	106.14[b]
Variance	135.52	1691.60	1063.54
Minimum	75.06	165.45	74.19
Maximum	133.39	343.71	210.32
Skewness	0.79	1.92	1.76
Kurtosis	1.09	3.25	2.62
Standard Deviation	11.64	41.13	32.61
N	72	72	72
Descriptive Statistics between January 2006 and April 2011			
Mean	179.43[a]	309.35[a]	129.92[a]
Variance	2539.46	5918.71	2430.86
Minimum	102.70	175.91	45.03
Maximum	318.45	452.19	262.95
Skewness	0.85	-0.21	0.36
Kurtosis	0.31	-1.05	0.02
Standard Deviation	50.39	76.93	49.30
N	64	64	64

[1] The difference between feeding the dLys levels that maximized profit (Maximum profit) and the dLys levels that recommended by the breeder (Conventional profit).
Means in a column with different letters (LSD multiple range test) differ significantly ($P < 0.05$).

Table 4.12 Descriptive statistics of dLys levels that maximized profit during grower and finisher phases, revenue, total cost, maximum profit, conventional profit and cost of making wrong decision between low volatile period (January 2000 to December 2005) and high volatile period (January 2006 to April 2011).

Descriptive Statistics	Grower dLys level %	Finisher dLys level %	Revenue Cent/bird	Total cost Cent/bird	Maximum profit Cent/bird	Conventional profit Cent/bird	Cost of making wrong decision[1] Cent/bird
Descriptive Statistics between January 2000 and December 2005							
Mean	1.25[a]	0.78	571.08[a]	211.40[b]	359.68[a]	356.93[a]	2.75
Variance	0.02	0.004	28.39	81.57	189.08	224.85	−35.77
Minimum	0.78	0.71	552.25	194.97	315.79	307.10	8.69
Maximum	1.30	0.95	575.34	236.46	378.72	376.41	2.31
Skewness	-2.52	0.63	-2.43	0.86	-1.61	-1.79	
Kurtosis	5.06	-0.18	4.92	0.60	2.41	2.99	
Standard Deviation	0.13	0.06	5.33	9.03	13.75	15.00	
N	72	72	72	72	72	72	
Descriptive Statistics between January 2006 and April 2011							
Mean	1.09[b]	0.77	565.27[b]	263.20[a]	302.07[b]	299.14[b]	2.93
Variance	0.03	0.01	56.82	1009.12	1316.84	1342.07	−25.23
Minimum	0.77	0.71	551.75	213.21	222.99	222.69	0.29
Maximum	1.30	1.05	576.69	349.35	359.63	357.55	2.07
Skewness	-0.06	1.74	0.0002	0.64	-0.36	-0.31	
Kurtosis	-1.40	2.00	-1.27	0.12	-0.42	-0.50	
Standard Deviation	0.18	0.10	7.54	31.77	36.29	36.63	
N	64	64	64	64	64	64	

[1] The difference between feeding the dLys levels that maximized profit (Maximum profit) and the dLys levels recommended by the breeder (Conventional profit).

Means in a column with different letters (LSD multiple range test) differ significantly ($P < 0.05$).

Figure 4.1 Historical corn and soybean meal prices and their spread (soybean meal price minus corn price) between January 2000 and April 2011

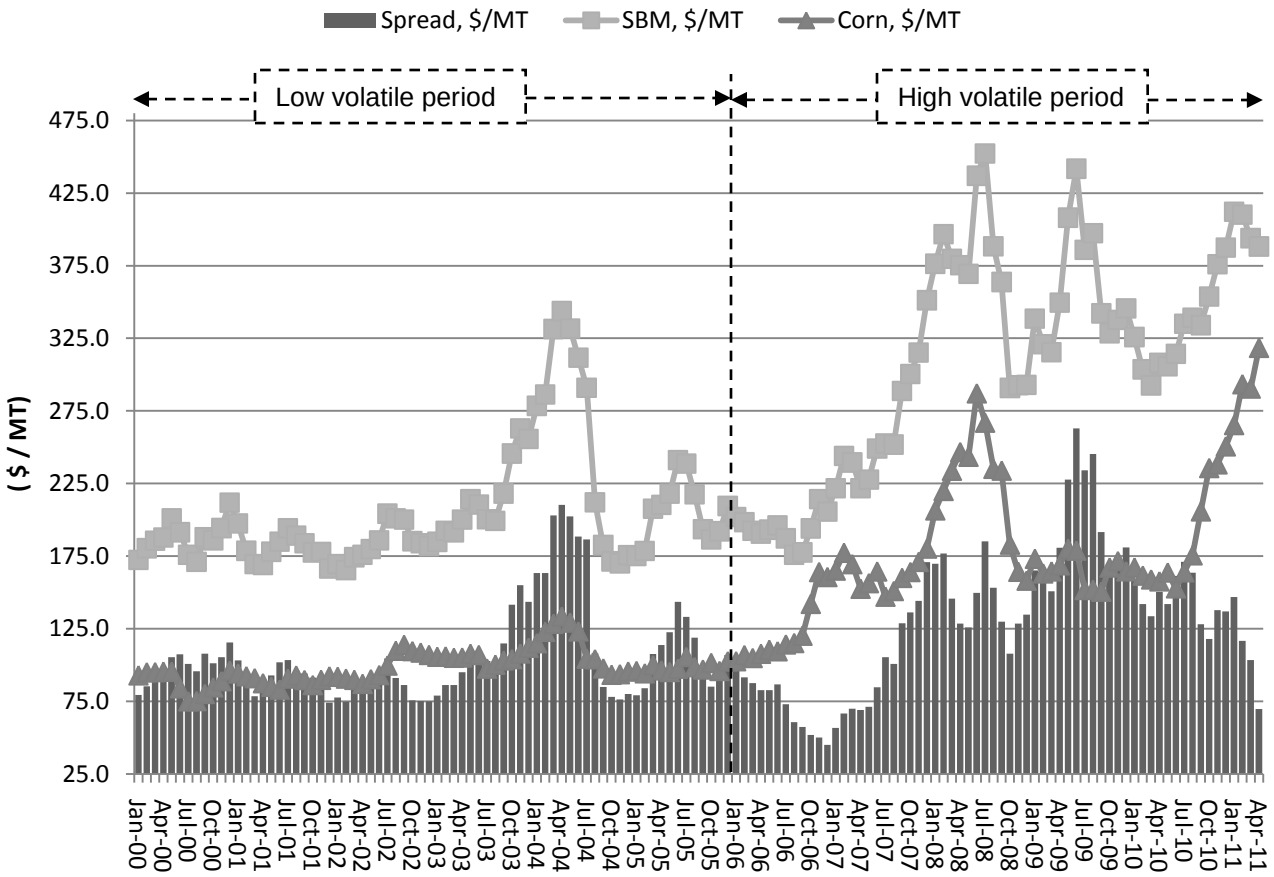
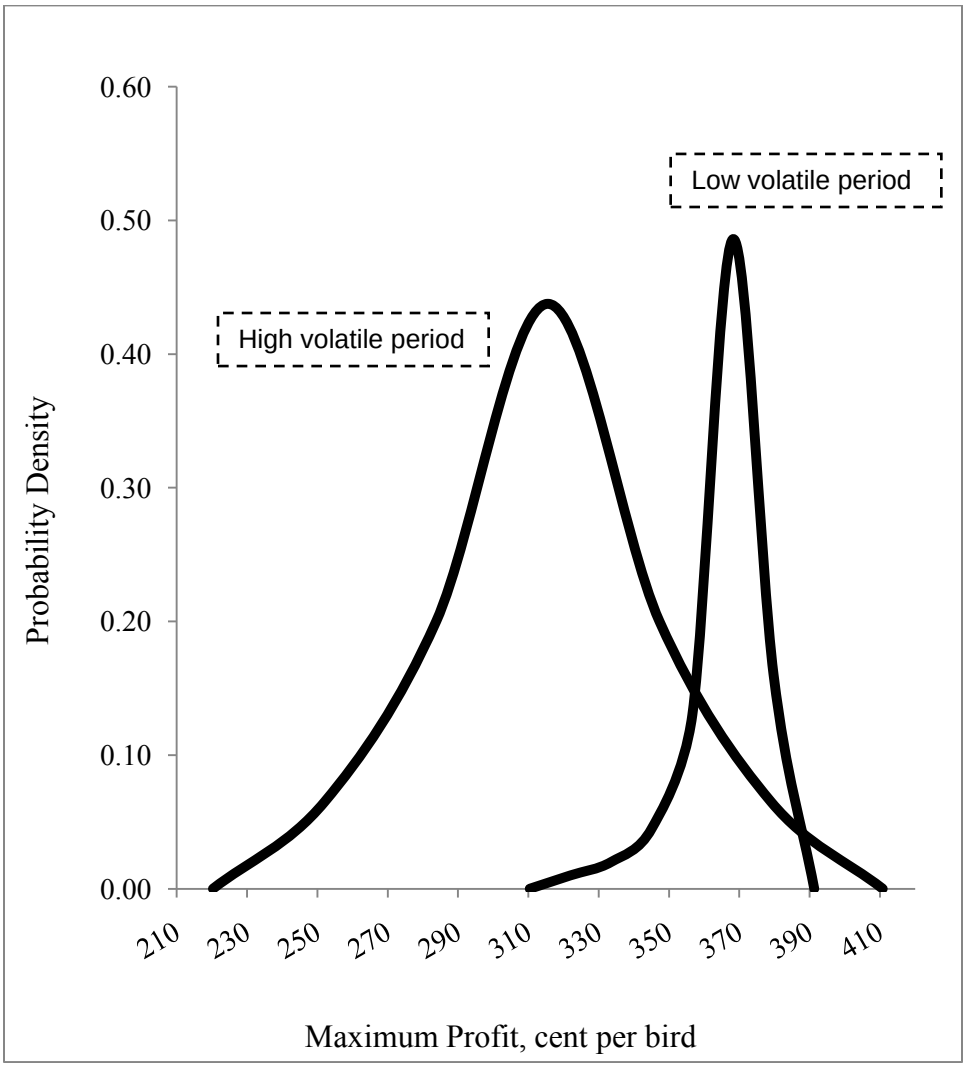


Figure 4.2 Probability distributions of maximum profit conditions during low (January 2000 to December 2005) and high (January 2006 to April 2011) volatile periods



CHAPTER 7

CONCLUSIONS

The objective of this research was to demonstrate that the broiler production decision, based on the targeted market for selling whole carcass or cut-up parts, can be evaluated using broiler growth performance information and a profit function. Nonlinear models of production functions, using broiler growth performance information, were used in the profit function to evaluate a profit-maximization condition that operated under Microsoft Excel spreadsheet. The spreadsheets make the analysis accessible to chicken producers and integrators. The profit model can determine the optimum conditions where a producer utilizes its production, inputs, and processing plant to obtain the maximum profit. This research showed that growth responses can vary depending on the maximum profit of feeding the formulated diet to broilers under various feed ingredient and broiler market prices. At constant output prices, increasing input costs decreases the size of bird that maximizes profits. Similarly, at constant input costs, increasing output prices increases the size of bird that maximizes profits. The marginal product of input (feed consumption) is the change in output (liveweight) as the change in feed consumption goes to zero. To maximize profit, the marginal product of feed consumption must be equal to the price of the feed consumed divided by the liveweight price. Profitability can be improved when revenue and costs are both considered in the formulation of broiler diets. Broiler growth and feed intake are two key components in determining the profit, which are not considered in traditional least-cost feed formulation.

In this research, an experiment was conducted to obtain the data necessary to evaluate the broiler production responses (body weight and feed intake) of dietary balanced protein (based on digestible lysine (dLys) level). The broiler diets used in this research were based on corn, soybean meal, meat and bone meal and synthetic amino acids to assure the dietary protein was balanced. The data collected from the experiment were used to estimate the production functions. Data used for economic analysis were obtained from a confidential survey conducted with a poultry company and the Georgia Department of Agriculture. The information contained prices of ingredients, production costs and targeted market prices.

The Cobb-Douglas (CD) production functions were adopted. The coefficients of the CD can be used to explain the elasticity among the variables. Results indicated that body weight of broilers increased about 0.87 percent for every one percent increased in feed intake. Analysis showed that broiler fed with one percent higher in dLys increased broilers' body weight by 0.06 and 0.08 percents during grower and finisher phases, respectively. Feed intake was analyzed as a function of time (number of grow-out day) and dLys levels during grower and finisher phases.

Results showed that feed intake increased about 1.74 percent for every one percent increase in the number of grow-out days. Analysis showed that broilers fed with one percent higher digestible lysine level (dLys) increased feed consumption by 0.01 during grower phase while decreasing feed consumption by 0.07 percent during finisher phases. Carcass and cut-up part weights were determined as functions of live body weight and dLys levels during grower and finisher phases. Results showed that carcass and cut-up part weights, except leg quarters and rest of carcass, increased as live body weight and the level of dLys in the diets increased. Thus, carcass and cut-up part weight can be improved by feeding higher level of dLys. This suggested that feeding broilers at higher dLys levels improved broiler market value.

The estimated production functions were used in the profit maximization analysis of the programming model. The optimum feeding levels of dLys were determined based on input costs, output prices and other fixed and variable costs of broiler production. The optimum broiler weight, number of grow-out day, feed consumption and feed formulation that provided the maximum profit was estimated. The profit function was defined as average price of a broiler (P_{BW}) times live body weight (BW), minus total cost (TC). The TC is the calculation of least-cost feed (r_{FC}) plus feed delivery cost (DEL) times feed consumed and interest (future cost accounted for feed consumption at d); plus the sum of grower cost (GRO) and field DOA and condemnation cost (FDOA) times broiler weight and interest (future value of chicken at d); plus fixed cost (TFC) such as chick cost, vaccination, supervising, and miscellaneous costs. The interest cost (I) was the calculation of $(1 + \frac{i}{365})^d$, where d is feeding days and i is the annual interest rate of the grower.

The programming model provided alternative options on targeted market of broilers either selling a whole carcass or cut-up parts. Moreover, the model also formulated the diets that maximized profit of broiler production. For all the scenarios studied here, the most profitable strategy of a broiler company was to target the market of selling cut-up parts. At constant output prices (broiler market prices), increasing input costs (feed cost) decreases the size of bird that maximizes profits. Likewise, at constant input costs, increasing output prices increases the size of bird that maximizes profits. These results agreed with previous published article by Pesti et al. (2009a and 2009b).

REFERENCES

Allison, J.R., and D. Baird. 1974. "Least-cost livestock production rations." *Southern journal of agricultural economics* 6(2):41-45.

Agri Stats, Inc. 2010. *Monthly Live Production*. 6510 Mutual Dr. Fort Wayne, IN 46825.

Ajinomoto Heartland LLC. 2009. *True Digestibility of Essential Amino Acids for Poultry*. Ajinomoto Heartland LLC, Chicago, IL.

Aviagen. 2007. *Ross 708 broiler performance objectives*. Aviagen, Newbridge, Scotland.

Baker, D., A. Batal, T. Parr, N. Augspurger, and C. Parsons. 2002. "Ideal ratio (relative to lysine) of tryptophan, threonine, isoleucine, and valine for chicks during the second and third weeks posthatch." *Poultry science* 81(4):485-494.

Beattie, B.R., and C.R. Taylor. 1985. *The Economics of Production*: John Wiley & Sons, Inc.

Black, J.R., and J. Hlubik. 1980. "Basics of Computerized Linear Programs for Ration Formulation." *Journal of Dairy Science* 63(8):1366-1378.

Brown, W.G., and G. Arscott. 1960. "Animal production functions and optimum ration specifications." *Journal of Farm Economics* 42(1):69-78.

Cerrate, S., and P. Waldroup. 2009a. "Maximum Profit Feed Formulation of Broilers: 1. Development of a Feeding Program Model to Predict Profitability Using non Linear Programming." *International Journal of Poultry Science* 8(3):205-215.

Cerrate, S., and P. Waldroup. 2009b. "Maximum Profit Feed Formulation of Broilers: 2. Comparison among Different Nutritional Models." *International Journal of Poultry Science* 8(3):216-228.

Coelli, T. 2005. *An introduction to efficiency and productivity analysis*: Springer Verlag.

Corzo, A. (2008) Maximizing production efficiency by a better understanding of the 4th limiting amino acid in broiler formulation. Timonium, Maryland, pp. 76-81.

Costa, E.F., B.R. Miller, J.E. Houston, and G.M. Pesti. 2001. "Production and profitability responses to alternative protein sources and levels in broiler rations." *Journal of Agricultural and Applied Economics* 33(3):567-582.

D'Mello, J. 2003. *Amino acids in animal nutrition*. CABI Publishing, Cambridge, MA.

Darmani Kuhi, H., E. Kebreab, S. Lopez, and J. France. 2009. "Application of the law of diminishing returns to estimate maintenance requirement for amino acids and their efficiency of utilization for accretion in young chicks." *The Journal of Agricultural Science* 147(04):383-390.

Douglas, P.H. 1976. "The Cobb-Douglas Production Function Once Again: Its History, Its Testing, and Some New Empirical Values." *The Journal of Political Economy* 84(5):903-916.

Dozier III, W., R. Gordon, J. Anderson, M. Kidd, A. Corzo, and S. Branton. 2006. "Growth, meat yield, and economic responses of broilers provided three-and four-phase schedules formulated to moderate and high nutrient density during a fifty-six-day production period." *The Journal of Applied Poultry Research* 15(2):312.

Eits, R., R. Kwakkel, M. Verstegen, and L. Hartog. 2005a. "Dietary balanced protein in broiler chickens. 1. A flexible and practical tool to predict dose–response curves." *British Poultry Science* 46(3):300-309.

Eits, R., G. Giesen, R. Kwakkel, M. Verstegen, and L. Den Hartog. 2005b. "Dietary balanced protein in broiler chickens. 2. An economic analysis." *British Poultry Science* 46(3):310-317.

Frontline Systems, Inc. 1999. Solver User's Guide. Incline Village, NV.

Emmert, J., and D. Baker. 1997. "Use of the ideal protein concept for precision formulation of amino acid levels in broiler diets." *The Journal of Applied Poultry Research* 6(4):462-470.

Frontline Systems, Inc. 1999. *Solver User's Guide*. Incline Village, NV.

Garrett, H., and C. Grisham. 2007. *Biochemistry*. Fort Worth: Thomson Learning.

Georgia Department of Agriculture. 19 Martin Luther King, Jr. Dr., S.W. Atlanta, Georgia 30334. http://agr.georgia.gov/portal/site.

Gonzalez-Alcorta, M.J., J.H. Dorfman, and G.M. Pesti. 1994. "Maximizing profit in broiler production as prices change: A simple approximation with practical value." *Agribusiness* 10(5):389-399.

Guevara, V. 2004. "Use of nonlinear programming to optimize performance response to energy density in broiler feed formulation." *Poultry science* 83(2):147-151.

Heady, E.O. 1957. "An econometric investigation of the technology of agricultural production functions." *Econometrica: Journal of the Econometric Society* 25(2):249-268.

Henderson, J.M., and R.E. Quandt. 1980. *Microeconomic Theory: A Mathematical Approach*. 3rd ed: McGraw-Hill Book Company.

Hyman, D.N. 1989. *Modern Micoreconomics: Analysis and Applications*. 2nd ed. North Carolina: Times Mirror /Mosby College Publishing.

Kennedy, J., B. Rofe, I. Greig, and J. Hardaker. 1976. "Optimal feeding policies for broiler production: an application of dynamic programming." *Australian Journal of Agricultural Economics* 20(01):19-32.

Kidd, M., and L. Hackenhaar. 2006. "Dietary threonine for broilers: dietary interactions and feed additive supplement use." *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources.*

Kmenta, J. 1967. "On Estimation of the CES Production Function." *International Economic Review* 8(2):180-189.

Lemme, A., C. Kemp, E. Fleming, and C. Fisher. 2008. Impact of increasing levels of balanced protein on biological and economic parameters of two different commercial broiler lines: Ross 308 and Ross 708. Brisbane, Australia.

Mack, S., D. Bercovici, G. De Groote, B. Leclercq, M. Lippens, M. Pack, J. Schutte, and S. Van Cauwenberghe. 1999. "Ideal amino acid profile and dietary lysine specification for broiler chickens of 20 to 40 days of age." *British Poultry Science* 40(2):257-265.

Mansfield, E. 1988. *Microeconomics: Theory and Applications*. 6th ed: W.W. Norton&Company, Inc.

Mendenhall, W., Sincich, T., 2003. *A second course in statistics: Regression analysis*. Pearson Education, Inc. NC, USA.

Miller, B.R., R.A. Arraes, and G.M. Pesti. 1986. "Formulation of broiler finishing rations by quadratic programming." *Southern journal of agricultural economics* 18(01):141-150.

Mills, G. 1984. *Optimisation in Economic Analysis*. 1st ed. UK: George Allen & Unwin (Publishers) Ltd.

Mundi, I. (2009) Historical Commodity Prices, Index Mundi. http://www.indexmundi.com/commodities/ .

Pesti, G., R. Arraes, and B. Miller. 1986. "Use of the quadratic growth response to dietary protein and energy concentrations in least-cost feed formulation." *Poultry science* 65:1040-1051.

Pesti, G.M., N. Sriperm, and M.E. Wetzstein. "Optimizing Broiler Profitability during Difficult Times-Part One: Impact of liveweight and carcass weight on optimizing profit." *Feedstuffs*, February 23, 2009a, pp. 16-17.

Pesti, G.M., N. Sriperm, and M.E. Wetzstein. "Optimizing Broiler Profitability during Difficult Times-Part two:Maximizing Profitability with Optimal Nutrient Density." *Feedstuffs*, May 25, 2009b, pp. 22-25.

Pesti, G., D. Vedenov, J. Cason, and L. Billard. 2009c. "A comparison of methods to estimate nutritional requirements from experimental data." *British Poultry Science* 50(1):16-32.

Romero, L., M. Zuidhof, R. Renema, F. Robinson, and A. Naeima. 2009. "Nonlinear mixed models to study metabolizable energy utilization in broiler breeder hens." *Poultry science* 88(6):1310-1320.

SAS User's Guide. 2004. Version 9.1 ed. SAS Inst. Inc., Cary, NC.

Sriperm, N., and G.M. Pesti. 2011. "Response Surface Analysis of Dietary Balanced Protein responses during grower and finisher phases of Ross 708 male broilers." Dissertation, University of Georgia.

Sterling, K., D. Vedenov, G. Pesti, and R. Bakalli. 2005. "Economically optimal dietary crude protein and lysine levels for starting broiler chicks." *Poultry science* 84(1):29-36.

Talpaz, H., S. Hurwitz, J.R. de la Torre, and P.J.H. Sharpe. 1988. "Economic optimization of a growth trajectory for broilers." *American Journal of Agricultural Economics* 70(2):382-390.

Timothy, J.C., D.S.P. Rao, C.J. O'Donnell, and G.E. Battese. 2005. *An introduction to eficiency and productivity analysis*. 2nd ed. Queensland: Springer Science and Business Media, Inc.

Tesseraud, S., R. Peresson, J. Lopes, and A. Chagneau. 1996. "Dietary lysine deficiency greatly affects muscle and liver protein turnover in growing chickens." *British Journal of Nutrition* 75(6):853-865.

Walters, A. 1963. "Production and cost functions: An econometric survey." *Econometrica: Journal of the Econometric Society* 31(1):1-66.

Wijtten, P., A. Lemme, and D. Langhout. 2004. "Effects of different dietary ideal protein levels on male and female broiler performance during different phases of life: single phase effects, carryover effects, and interactions between phases." *Poultry science* 83(12):2005-2015.

Zellner, A., J. Kmenta, and J. Dreze. 1966. "Specification and estimation of Cobb-Douglas production function models." *Econometrica: Journal of the Econometric Society* 34(4):784-795.

Zuidhof, M.J. (2009) Nonlinear Effects of Diet on Broiler Production. Rogers, Arkansas.

APPENDIX A

Table A 1.1 Production costs used in the profit maximization analysis

Variables	Abbreviation	Values	Unit
Interest Cost	I	1.01	%
Feed Cost	r_{FC}	29.85	Cent/lb
Chick Costs	TFC	29.79	Cent/chick
Vaccination, Supervising, Miscellaneous	TFC	1.61	Cent/chick
Grower Costs	GRO	6.06	Cent/lb
Milling and Delivery Cost	DEL	1.50	Cent/lb
DOA and Field Condemnation Cost	FDOA	0.33	Cent/lb
Cost of Catching and Hauling	CH	1.45	Cent/lb
Processing Cost	PC		
Step 1: Including all fixed overhead		7.50	Cent/lb
Step 2: Cutting and Packaging		9.75	Cent/lb
Total Cost		386.07	Cents / bird

APPENDIX B

Table B 1.1 Corn and soybean meal prices and their spread (soybean meal minus corn)

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Jan-00	92.95	172.43	79.48
Feb-00	95.08	180.47	85.39
Mar-00	95.17	185.63	90.46
Apr-00	95.54	187.86	92.32
May-00	95.53	200.98	105.45
Jun-00	84.04	191.49	107.45
Jul-00	75.06	175.93	100.87
Aug-00	75.24	171.07	95.83
Sep-00	80.15	188.03	107.88
Oct-00	84.71	186.00	101.29
Nov-00	88.94	194.33	105.39
Dec-00	96.22	211.81	115.59
Jan-01	94.30	197.59	103.29
Feb-01	92.38	178.71	86.33
Mar-01	91.01	169.52	78.51
Apr-01	87.55	169.02	81.47
May-01	85.08	178.07	92.99
Jun-01	83.16	185.04	101.88
Jul-01	90.75	194.23	103.48
Aug-01	92.88	189.10	96.22
Sep-01	89.74	183.94	94.20
Oct-01	86.27	177.63	91.36
Nov-01	89.88	177.99	88.11
Dec-01	92.31	166.50	74.19
Jan-02	91.97	169.58	77.61
Feb-02	90.73	165.45	74.72
Mar-02	89.86	174.29	84.43
Apr-02	87.11	175.93	88.82
May-02	90.33	179.90	89.57
Jun-02	93.17	185.83	92.66
Jul-02	99.70	204.24	104.54
Aug-02	109.89	201.12	91.23
Sep-02	113.94	200.25	86.31
Oct-02	109.65	185.35	75.70
Nov-02	108.65	183.88	75.23
Dec-02	107.01	181.98	74.97
Jan-03	105.75	184.87	79.12
Feb-03	106.04	192.42	86.38
Mar-03	105.06	191.36	86.30
Apr-03	105.25	200.26	95.01
May-03	107.82	214.18	106.36
Jun-03	106.99	210.61	103.62
Jul-03	97.61	200.44	102.83
Aug-03	100.31	199.30	98.99
Sep-03	103.22	218.14	114.92
Oct-03	104.17	245.71	141.54
Nov-03	108.03	262.96	154.93
Dec-03	111.98	255.64	143.66
Jan-04	115.09	278.48	163.39
Feb-04	122.91	286.39	163.48
Mar-04	128.43	331.41	202.98
Apr-04	133.39	343.71	210.32
May-04	129.30	331.65	202.35
Jun-04	123.23	311.68	188.45
Jul-04	104.48	291.01	186.53
Aug-04	104.04	212.15	108.11
Sep-04	97.76	182.69	84.93
Oct-04	93.37	171.44	78.07
Nov-04	93.75	170.13	76.38
Dec-04	95.59	175.72	80.13
Jan-05	95.98	175.18	79.20
Feb-05	94.36	178.55	84.19
Mar-05	99.94	207.64	107.70
Apr-05	96.39	210.27	113.88
May-05	95.27	218.01	122.74
Jun-05	97.56	241.22	143.66
Jul-05	105.60	238.80	133.20
Aug-05	98.64	217.60	118.96
Sep-05	96.99	193.57	96.58
Oct-05	101.50	186.58	85.08
Nov-05	95.97	192.15	96.18
Dec-05	102.66	209.58	106.92
Jan-06	102.70	201.96	99.26
Feb-06	106.92	198.43	91.51
Mar-06	104.89	192.43	87.54
Apr-06	107.82	190.55	82.73
May-06	110.57	193.25	82.68
Jun-06	109.55	196.26	86.71
Jul-06	114.24	187.27	73.03
Aug-06	115.21	175.91	60.70

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Sep-06	120.26	177.59	57.33
Oct-06	142.17	194.12	51.95
Nov-06	164.08	214.23	50.15
Dec-06	160.66	205.69	45.03
Jan-07	165.10	221.79	56.69
Feb-07	177.35	244.10	66.75
Mar-07	169.52	239.53	70.01
Apr-07	152.58	221.75	69.17
May-07	156.44	227.67	71.23
Jun-07	164.50	249.16	84.66
Jul-07	147.13	252.57	105.44
Aug-07	151.01	251.83	100.82
Sep-07	160.05	288.78	128.73
Oct-07	164.09	300.43	136.34
Nov-07	171.06	315.25	144.19
Dec-07	180.25	351.22	170.97
Jan-08	206.53	376.33	169.80
Feb-08	219.95	396.71	176.76
Mar-08	233.85	379.70	145.85
Apr-08	246.67	375.32	128.65
May-08	243.46	369.37	125.91
Jun-08	287.11	436.91	149.80
Jul-08	266.94	452.19	185.25
Aug-08	235.16	388.40	153.24
Sep-08	233.91	363.78	129.87
Oct-08	182.96	290.84	107.88
Nov-08	164.27	292.76	128.49
Dec-08	158.16	292.94	134.78
Jan-09	173.24	338.50	165.26
Feb-09	163.13	320.89	157.76
Mar-09	164.52	315.37	150.85
Apr-09	168.72	349.57	180.85
May-09	180.31	408.05	227.74
Jun-09	178.83	441.78	262.95
Jul-09	151.76	385.85	234.09
Aug-09	152.01	397.30	245.29
Sep-09	150.57	342.18	191.61
Oct-09	167.22	328.54	161.32
Nov-09	171.61	337.63	166.02
Dec-09	164.58	345.58	181.00
Jan-10	167.21	325.85	158.64
Feb-10	161.63	303.66	142.03
Mar-10	159.01	292.60	133.59
Apr-10	157.66	308.05	150.39
May-10	163.77	305.74	141.97
Jun-10	152.87	314.32	161.45
Jul-10	163.92	335.09	171.17
Aug-10	175.60	339.14	163.54

Month / Year	Corn, $/MT	SBM, $/MT	Spread, $/MT
Sep-10	205.84	334.06	128.22
Oct-10	235.70	353.75	118.05
Nov-10	238.24	376.04	137.80
Dec-10	250.63	387.51	136.88
Jan-11	265.29	412.07	146.78
Feb-11	293.40	410.16	116.76
Mar-11	290.43	393.93	103.50
Apr-11	318.45	388.22	69.77