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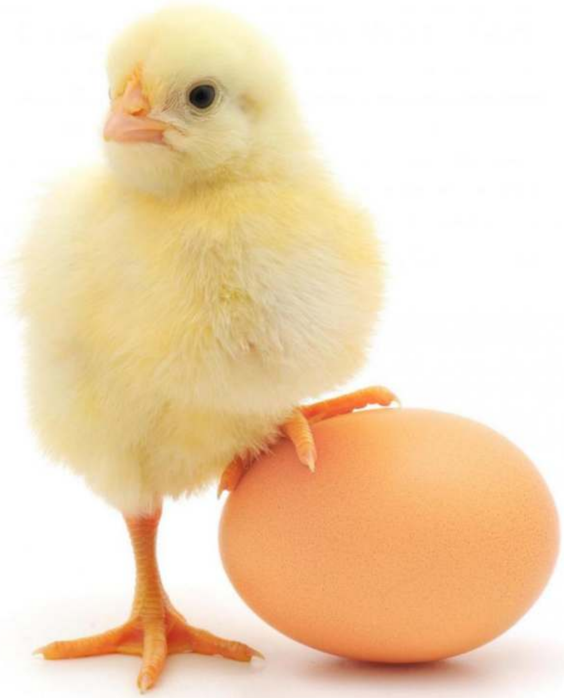

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ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

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Maximum Profit Feed Formulation of Broilers: 1. Development of a Feeding Program Model to Predict Profitability Using non Linear Programming[1]

Sandro Cerrate and Park Waldroup[2]
Department of Poultry Science, University of Arkansas, Fayetteville AR, USA

Abstract: Maximum Profit Feed Formulation (MPFF) is proposed as a new approach to formulation of broiler diets which predicts the best profit for given ingredient and broiler prices, nutrient requirements and performance. Absolute and relative equations for body weight and feed intake as a function of Dietary Nutrient Density (DND) were developed and included into the objective function of Maximum Profit Programming 3.0. Maximum performance and profitability were compared in terms of DND. Factors such as livability, temperature, processing cost, ingredient and broiler prices, starting and ending broiler prices as well as comparisons of two dynamic models, Body Weight (BW) or cut-up parts (CW), were evaluated to determine changes in DND and to compare the profitability between MPFF and Least-cost Feed Formulation (LCFF). Starter, grower and finisher DND were calculated from the mean of DND obtained by the MPFF. The maximum performances for cut-up parts and body weight were 3.250 and 3.300 ME kcal/g of DND respectively using simulations of the calculated equations, whereas the maximum profits for them were at 3.169 and 3.177 ME kcal/g respectively using the MPFF. Livability slightly decreased the DND, while temperature and processing cost did not affect the DND. However, the ingredient and broiler prices did affect the DND. As broiler meat or corn price increased, the DND was also increased but as the price of soybean meal or poultry oil increased, the DND tended to decrease. For the above variables, use of the MPFF resulted in better profits than did use of LCFF. As expected, the use of ending broiler prices produced better profitability than use of starting broiler prices. If the starting broiler prices were used, the MPFF resulted in higher profits than with LCFF and had similar pattern in profits as ending prices. The dynamic model CW estimated a narrower range of DND compared with those of dynamic model BW. Both dynamic models were more profitable than those of the LCFF model. Starter, grower and finisher DND decreased as the bird aged. This new formulation method can be used to complement least cost formulation to get the best profitability and is recommended for Ross male lines (on which the performance data was developed) with the static nutrient requirement and ingredients used. Requirements for other strains should be quantified by dose-response.

Key words: Maximum profit programming, Least-cost feed formulation, broilers feed

INTRODUCTION

In conventional Least-cost Feed Formulation (LCFF), the formulator establishes a set of nutrient requirements (restrictions) that are fixed in nature, but are usually intended to maximize performance (body weight gain or feed utilization). Although some modifications may be made in the formulation, such as formulating for optimum nutrient density, the profitability of the broiler enterprise may not be maximized when rigid nutrient specifications are imposed. Fluctuations in price of ingredients, variation in performance due to differences in nutrient levels and variation in value of the resulting product should determine the nutritional requirements in order to reach the best profits because this is the business objective of modern poultry enterprises.

In contrast, Maximum Profit Feed Formulation (MPFF) formulates diets considering nutrient requirements, price variations of ingredients and value of broiler meat. In addition, this new approach to formulation can increase or decrease the nutrient restrictions as well as the performance related to the maximum profitability; however, the LCFF keeps the nutrient requirement constant for a given performance and therefore for a given profit.

Many investigations have proposed diet formulation models for maximum profitability (McDonald and Evans, 1977; Greig *et al*., 1977; Allison *et al*., 1978; Pesti *et al*., 1986; Gonzalez-Alcorta *et al*., 1994) which were based on diminishing marginal productivity. This law of diminishing returns means that as nutrient requirements increases the performance, e.g. body weight, also increases, but a decreasing rate. As a result, non-linear programming has recently been used to formulate diets from predicted profitability calculated based upon body weight and feed consumption as function of Dietary Nutrient Density (DND) (Guevara, 2004) or dietary lysine and crude protein intake (Sterling *et al*., 2005).

In order to quantify only the effect of DND on performance and not include particular environmental effects of research trials, it is necessary to express the performance in relative terms (Pack *et al.*, 2003). At the present, the proposed models recommended a single diet for the feeding time (Pesti *et al.*, 1986; Sterling *et al.*, 2005; Guevara, 2004), an approach that is not considered practical due to declining needs for many nutrients (expressed as a percentage of the diet) as the bird aged. Thus, a feeding program model of maximum profit feed formulation should determine a mean of the DND of feeding phases which represents the energy content of starter, grower or finisher. On the other hand, to ensure a good quality carcass, it is necessary to maintain a fairly consistent calorie: nutrient ratio. An increase in dietary energy through the addition of fat without altering the calorie: protein ratio had no adverse effect on carcass fat content (Bartov *et al.*, 1974; Bartov, 1977) or abdominal fat (Saleh *et al.*, 2004) of the broilers.

In addition to price variations of ingredients and broiler meat that can change nutrient requirements in order to obtain the best profits, factors such as livability, temperature and processing cost may affect the nutrient requirements. Furthermore, the diet formulation models for maximum profitability cited to date consider the broiler price at the beginning of the formulation to calculate the profitability. However, the broilers are sold days later and can be a different price at that time. In the United States, the majority of the consumption of poultry is in the form of cut-up parts (50%) and further processed (40%). Recently, a maximum profit feeding program based on cut up parts had recommended more protein than those that included carcass weights (Costa and Houston, 2004).

The present study has four objectives: 1) to evaluate the effects of changes of ingredient costs, wholesale prices, livability, temperature and processing cost on Dietary Nutrient Density (DND) 2) to calculate the use of two kinds of broiler prices in the MPFF, 3) to compare the DND from the prediction of body weight or cut-up parts and 4) to see differences in profitability for the above mentioned variables between the MPFF and LCFF.

MATERIALS AND METHODS

Data from a dose-response experiment by Saleh *et al.* (2004) was used to quantify the effects of DND on body weight, feed consumption, carcass weight or cut-up parts of Ross male broilers. In this study the essential dietary nutrients were maintained in a constant relationship to dietary energy. For practical use of the model the DND was represented by the level of Metabolizable Energy (ME) which was calculated as the average energy content of starter, grower and finisher diets. The body weight and feed consumption were expressed in relative values to quantify only the effects of DND. This relative performance was then transformed back to absolute values.

Development of the model to predict profitability

Actual body weight and feed consumption equations: The actual Body Weight (aBW) and Feed Consumption (aFC) were obtained by the multiplication of relative and absolute values for both body weight and feed consumption.

$$aBW = rBW \times bBW$$

$$aFC = rFC \times bFC$$

Where: rBW = relative body weight, rFC = relative feed consumption, bBW = absolute body weight and bFC = absolute feed consumption.

Relative body weight and feed consumption equations: The relative Body Weight (rBW) and Feed Consumption (rFC) were expressed in terms of metabolizable energy from recalculated data of Saleh *et al.* (2004) at 49 days by quadratic equations, making use of Microsoft Excel (2003) spreadsheet. The recalculated data were calculated by the division of original data [Body Weight (oBW) and Feed Consumption (oFC)] over estimated data [Body Weight (eBW) and Feed Consumption (eFC)]. Estimated data were also expressed in term of DND from the original data of Saleh *et al.* (2004) at 49 days by quadratic equations. These equations were fixed to 3.2 kcal/g of DND (Table 1).

eBW = $-1.8736x\ DND^2 + 12.287x\ DND - 17.382$; $R2 = 0.6998$
eFC = $-3.121x\ DND^2 + 19.545x\ DND - 25.372$; $R2 = 0.5359$
rBW = oBW / eBW (ME=3.2); rFC = oFC / eFC (ME=3.2)

Absolute body weight and feed consumption equations: The absolute Body Weights (bBW) were predicted from the final day of the feeding phase (day 49) by the use of the Gompertz equation (Gompertz, 1825). The coefficients (A, B and C) of this equation were obtained from the body weight of the Cobb-Vantress Guide (2003) and its respective day making use of the solver tool in *Maximum Profit programming 3.0* (Table 2)

$$bBW = 6.621*EXP[-EXP\ \{-0.039*(days-39.965)\}]$$

Where: A = weight of maturity, 6.621, B = rate of growth, 0.039 and C = day when the weight gain is the highest, 39.965.

The absolute Feed Consumptions (bFC) were predicted from the absolute Body Weight (bBW) by the use of a quadratic equation. The coefficients (a, b and c) of this equation were obtained from the average accumulative feed consumption from Saleh *et al.* (2004) data and its respective body weight, making use of an Excel XP (2003) spreadsheet (Table 2).

The basic shape of this feed consumption curve has remained constant during over time and there are only small changes in the slope of this equation (Pesti and Rogers, 1997) for several performances (NRC, 1984; 1994).

Table 1: Original and relative body weight and feed consumption values at 49 days

DND Kcal/g	oBW kg	oFC kg	rBW	rFC
3.023	2.652	5.257	0.96	1.01
3.069	2.679	5.138	0.97	0.99
3.109	2.702	5.257	0.98	1.01
3.148	2.698	5.154	0.98	0.99
3.188	2.757	5.230	1.00	1.00
3.227	2.720	5.146	0.99	0.99
3.267	2.816	5.247	1.02	1.01
3.304	2.780	5.214	1.01	1.00
3.344	2.741	5.072	1.00	0.97
3.383	2.727	4.979	0.99	0.96
	eBW (ME)	eFC(ME)		
3.2	2.751	5.213	1.00	1.00

Where: oBW or oFC = original body weight or feed consumption respectively. rBW or rFC = relative body weight or feed consumption respectively. eBW or eFC = estimated body weight and feed consumption respectively. DND = dietary nutrient density

Table 2: Absolute body weight and feed consumption

Day of age	Body weight[1]	Body weight[2]	Feed intake[2]
0	0.045		
7	0.165		
14	0.435		
21	0.831	0.715	0.956
28	1.356		
35	1.962		
42	2.616	2.181	3.822
49	3.278	2.727	5.169
56		3.194	6.479
63		3.677	7.906

[1] From Cobb -Vantress data (2003). [2] From Saleh *et al*. (2004) data

Relative body weight and feed consumption as a function of temperature: The relative Body Weight (tBW) and Feed Consumption (tFC) as a function of temperature were obtained from calculated data of Cheng *et al*. (1997a,b) for 21-49 days by quadratic equations, making use of Microsoft Excel (2003) spreadsheet.

Carcass weight and breast meat, wing, leg and thigh part estimations: The Carcass Weights (CW) were estimated from the multiplications of the actual Body Weight (aBW) at 49 day and the Dressing Percent (DP).

$$CW = aBW \times DP/100$$

The dressing percent were expressed in terms of DND from the data of Saleh *et al*. (2004) at 63 day by a quadratic equation, making use of Microsoft Excel (2003) spreadsheet. The absolute Breast Meat (BM), Thighs (T), Drumstick (D) and Wings (W) were estimated by the multiplications of Carcass Weight (CW) and the constant of each cut up part.

$$BM, T, D \text{ and } W \text{ (kg)} = CW \text{ (kg)} \times Constant_{(BM,\ T,\ D \text{ and } W)} (\%) \ / \ 100$$

A summary of the equations are listed in Table 3.

The programming model: The profitability was calculated considering the income over the total costs.

$$MP = Income\text{-}costs$$

Where MP = Maximum Profit, $/bird at 49 day, Income = BM, T, D and W (kg) x Price of each one ($/kg) or aBW x Price of live weight and Costs = aFC (kg) x cost of the diet ($/kg) + cost for live bird + processing cost.

The model was formulated in the *Maximum Profit programming 3.0*. This program has nonlinear programming and conventional linear programming using Solver, which is the default solver of Excel (Frontline Systems Inc., 1999). It uses the generalized reduced gradient method to solve nonlinear problems. The options, which are specified by the user, were set as follows: iterations = 1000, precision = 0.000000001, convergence = 0.000001, estimates = tangent, derivatives = forward and search = Newton. The composition matrix used in this program is listed in Table 4 and the static nutrient requirements are listed in Table 5.

The non-feed cost was considered $ 0.447 per broiler assuming 23% of $ 1.66 per bird which is the total cost of broiler production (Arraes, 1983). The processing cost was estimated as $0.733 per broiler from average live weight equivalent and Ready to Cook (RTC) prices published by USDA in 2006 and using the following equation:

Processing cost $/ bird (0.733) = [(Live weight equivalent price (0.851$/kg) / dressing percentage (0.774)) - RTC price (1.419$/kg)] (0.319 $/kg) x Carcass weight (2.3 kg)

The model identifies the combinations of feed ingredients to find the DND that maximizes the profitability (Table 6). The model requires the static nutrient requirements, cost of ingredients, price of the product and levels of DND which are entered as an extra ingredient. Further the response functions of body weight or cut-up parts and feed consumption were expressed in terms of DND.

Design of the analysis: The profitability was calculated with ranges from 3.0-3.35 ME kcal/g with an increment of 0.05 kcal/g and from 3.1-3.2 ME kcal/g with an increment of 0.025 kcal/g for dynamic model BW which includes the quantification of body weight, feed consumption and cost for live bird and for dynamic model CW which includes the quantification of cut-up parts, feed consumption, cost for live bird and processing cost. Further the MPFF was used in these two types of dynamic models.

Table 3: Summary of the equations present in the models

Dependent	Independent	Equations
rBW, kg/kg	ME, kcal/g	$rBW = -0.6811433ME^2+4.4667604ME-6.3191018$
bBW, kg	Days	bBW = 6.621xEXP(-EXP(-0.039x(days-39.965)))
tBW, kg/kg	T, °C	$tBW = -0.00305xT^2 + 0.13369xT - 0.46769$
aBW, kg	rBW, bBW, tBW	aBW = rBW x bBW x tBW
DP, %	ME, kcal/g	$DP = -35.477xME^2+ 224.51ME - 277.09$
BM, kg	DP, aBW	BM = 23 x DP x aBW/100
T, kg	DP, aBW	T = 16.3 x DP x aBW/100
D, kg	DP, aBW	D = 14.1 x DP x aBW/100
W, kg	DP, aBW	W = 11.1 x DP x aBW/100
Income total, IT		
(CW)		IT = BMxPriceBM + TxPriceT + DxPriceD + WxPrice W
(BW)		IT = aBW x Price of live weight
rFC, kg/kg	ME	$rFC = -0.5987ME^2 + 3.7493ME - 4.8671$
bFC, kg	bBW	$bFC = 0.2629bBW^2 + 1.1942bBW - 0.0328$
tFC, kg/kg	T, °C	$tFC = -0.00222xT^2 + 0.09082xT + 0.05778$
aFC, kg	rFc, bFC, tFC	aFC =rFC x bFC x tFC
Cost total		
(CW)		Cost total = aFCxCost of diet + cost for live bird + process cost
(BW)		Cost total = aFCxCost of diet + cost for live bird
Profitability (P), $/bird		P = Income total -cost total

rBW, bBW and aBW = relative, absolute and actual body weight respectively. rFC, bFC and bFC = relative, absolute and actual feed consumption respectively. tBW and tFC = relative body weight and feed consumption in function of temperature respectively. ME = metabolizable energy; T = Temperature. DP = dressing percent; BM = breast meat; T = thighs; D = drumstick; W = wings. CW and BW = cut up parts or carcass weight and body weight respectively

Table 4: Composition matrix of ingredients in the nonlinear programming model[1]

Ingredient	ME Kcal/g	CP	Ca	NPP	Na	Lys	Met	TSSA	Cost[2] $/kg	Min.	Max.
		---			%			--		--------- %	--------
Corn	3.35	8.5	0.02	0.08	0.02	0.26	0.18	0.36	0.151	0	100
Soybean meal	2.44	48.5	0.27	0.22	0.02	2.96	0.67	1.39	0.205	0	100
Poultry fat	8.25	-----	-----	-----	-----	-----	-----	-----	0.419	0	8
Limestone	-----	-----	38	-----	-----	-----	-----	-----	0.034	0	100
Phosphorus	-----	-----	21	16	-----	-----	-----	-----	0.281	0	100
Common salt	-----	-----	-----	-----	39	-----	-----	-----	0.061	0	100
Vitamin premix	-----	-----	-----	-----	-----	-----	-----	-----	3.700	0.1	0.1
Mineral premix	-----	-----	-----	-----	-----	-----	-----	-----	1.746	0.1	0.1
DL-Methionine	3.68	57.52	-----	-----	-----	-----	98	0.98	2.533	0	100
L-Lysine HCl	4.60	94.4	-----	-----	-----	74.42	-----	-----	1.762	0	100
ME										3.023	3,383
Minimum[3]	3.145	22.125	0.9	0.45	0.179	1.303	0.566	0.995			
Maximum	100	100	100	100	100	100	100	100			

[1]The Metabolizable Energy (ME) was allowed to vary from 3.023-3.383 kcal/g; these levels were utilized by Saleh *et al*. (2004).
[2]Reference prices for corn and soybean meal from the month of March of 2007. [3]The nutritional compositions for the ingredients were from NRC (1994) and the static nutrient requirements were from Cobb Vantress (2003). Where: ME = metabolizable energy; CP = crude protein; Ca = calcium; NPP = nonphytate phosphorus; Na = sodium; Lys = total lysine; Met = total methionine; TSSA = total sulfur amino acids

Table 5: Static nutrient requirements from Cobb Vantress (2003)

Nutrients	Mixed starter	Mixed grower	Mixed finisher	Average
Protein %	23	22	21	22.125
ME, kcal/g	3.07	3.166	3.226	3.145
Lysine %	1.4	1.3	1.16	1.303
Methionine %	0.6	0.57	0.51	0.566
Met+Cys %	1.04	1	0.92	0.995
NPP %	0.45	0.45	0.45	0.450
Calcium %	0.9	0.9	0.9	0.900
Sodium %	0.2	0.17	0.16	0.179

[1]Average nutrient = (Nutrient-starter x 21 + Nutrient-grower x 21 + Nutrient-finisher x 14) / 56, ME = metabolizable energy; NPP = nonphytate phosphorus

The variations of livability (100% to 94%), temperature (21-26 C), processing cost and price for broilers, corn, soybean meal and poultry fat were evaluated to see the effects on DND using the MPFF. The prices of corn, soybean and broiler meat between March, 2006 and April, 2007 published by the USDA were used to formulate with two kinds of broiler prices, the starting and ending prices for broiler meat. The starting price was the price that had been formulated at the beginning of the feeding but the final price, after two months, was the price at which the broiler had been sold. After the formulations were made for LCFF and MPFF with

Table 6: Non linear programming model

Activity	Ingredients X1	X2	X3	Energy DND	Dynamic nutrient requirement Dynamic	constraints	Static nutrient requirement
Cost	c1	c2	c3				
Energy	e1	e2	e3		Ex	Ex – (ME/ME)xDND >= 0	ME
Protein	p1	p2	p3		Px	Px – (P/ME)xDND >= 0	P
Amino acid	a1	a2	a3		Ax	Ax – (A/ME)xDND >= 0	A
Minimum	0	0	0	DND1			
					DND		
Maximum	100	100	100	DND2			
Objective function:		Maximize		Profit = Income total (BW or CW) - cost total (BW or CW)			

Where: Ex, Px, Ax are amount of nutrient in the diet; DND = dietary nutrient density calculated by the program; ME, P and A are static requirement recommended by Cobb Vantress (2003); FC = feed consumption. Income total for BW: Body weight (fDND) x Price of live weight; Income total for CW: Cut-up parts (f(DND) x prices of each parts. Cost total for BW: Feed intake (fDND) x cost of the diet + cost for live bird; Cost total for CW: Feed intake (fDND) x Cost of diet + cost for live bird + process cost

starting and ending prices, the profitability for the three kinds of diets was calculated with the ending prices. Since in this new model of formulation the use of starting price is required to formulate since we have no idea what the ending prices will be, it is interesting to compare these two types of prices in relation with the LCFF. In this comparison we could observe that the diets formulated with ending price or real price will be more profitable than those with starting price or the LCFF; however, we could see the behavior of profitability between diets of starting price and LCFF. The broiler prices of cut up parts were calculated from the sum of whole bird price (10%) and processing carcass price (90%). The price of corn, soybean meal and poultry meat between April, 2006 and March, 2007 published by the USDA were used to formulate in LCFF and MPFF for Dynamic model BW and Dynamic model CW (Table 7).

Calculation of ME of each phase from average DND: After the DND was obtained from the non linear programming, the next step was to calculate the ME for each period of feeding by linear equations. The average DND were calculated from the average of ME of starter, grower and finisher diets of Saleh *et al.* (2004). After this, the ME of each phase and average DND were regressed by linear way. The average DND was used for two reasons: 1) to quantify the interactions between phases of feeding 2) to calculate an average feeding cost by DND in order to estimate an accurate cost of feeding.

RESULTS AND DISCUSSION

The developed equations were used to calculate the profitability for both types of dynamic models (Table 8). The maximum performances for cut-up parts and body weight were 3.250 ME kcal/g and 3.300 ME kcal/g of DND respectively. However, the maximum profitability for cut-up parts and body weight was 3.175 ME kcal/g. In these simulations the calculated profitability was not as accurate in finding best DND since it changed every 0.05 or 0.025 kcal/g. Using the maximum profit feed formulation, the DND for cut-up parts and body weight was 3.169 and 3.177 ME kcal/g respectively.

Variations of livability, temperature, processing cost and price for broiler, corn and soybean meal are presented in Table 9. The livability affected the DND only slightly. When this variable decreased, the Maximum Profit Feed Formulations (MPFF) had formulated diets with a slightly decreased DND. Decreased livability reduced the income in a constant way by decreasing the body weight or cut-up parts; this reduction of livability from 100- 94% only decreased the ME from 3.172-3.167 kcal/g. As the temperature increased, the DND remained almost constant, likely because the temperature affects the relative growth and feed consumption almost in similar proportions. The processing cost did not affect the DND. Though this cost affects the profitability, it does not influence the feed intake or body weight responses. Therefore, it is interesting to note that any variable included in the model to predict profitability that does not affect performance will not change the dynamic nutritional requirements.

When broiler prices increased, the MPFF had increased DND possibly because the carcass weight was increased in relation to DND. Guevara (2004) also found the same tendency. As the broiler price increased, the levels of corn were decreased, whereas the levels of soybean meal and poultry fat were increased. When the price of corn was increased, the DND also was increased. Even though the levels of corn in the diets tended to decrease, the levels of poultry fat and soybean meal tended to increase, consequently the nutrient density tended to increase. On the other hand, in the quadratic model proposed by Gonzalez-Alcorta *et al.* (1994) which included energy and protein, as the price of corn increased, the energy level decreased and protein level increased.

As the price of soybean meal increased, the DND tended to decrease. The levels of soybean meal and poultry fat in the diets were also decreased but the levels of corn were increased. Similar results were found by

Table 7: Prices of corn, soybean meal and poultry meat between April, 2006 and March, 2007

Variables	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
LEP		0.758	0.770	0.853	0.898	0.918	0.917	0.865	0.878	0.887	0.955	1.048	1.095	1.093
Whole carcass	1.362	1.299	1.313	1.421	1.479	1.505	1.503	1.437	1.454	1.466	1.553	1.673	1.734	1.731
Breast boneless	2.202	2.127	2.469	2.799	2.856	2.946	2.855	2.273	2.102	2.534	2.806	3.182	3.362	3.655
Thighs	0.616	0.608	0.800	0.921	0.983	1.060	0.966	0.815	0.821	0.955	1.072	1.178	1.247	1.294
Leg, whole	0.616	0.608	0.800	0.921	0.983	1.060	0.966	0.815	0.821	0.955	1.072	1.178	1.247	1.294
Wings	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680	1.680
Average	0.928	0.904	1.029	1.141	1.176	1.218	1.174	1.005	0.973	1.100	1.197	1.316	1.378	1.452
Corn	0.081	0.087	0.093	0.090	0.092	0.082	0.079	0.110	0.133	0.137	0.145	0.154	0.151	0.136
SBM	0.175	0.175	0.176	0.178	0.169	0.160	0.169	0.178	0.191	0.181	0.191	0.209	0.205	0.189

Average of cut up parts = [(Breastx0.23+Thighsx0.163+Drumstickx0.141+Wingx0.111)x0.9 + Wholecarcassx0.1], Note: Whole carcass = 12 city avg.; Northeast prices for breast boneless, legs whole. Wings price assumed constant; Wholesale value: Average value of the meat as it leaves the packing plant, measured in cents per pound of retail weight. Decatur soybean meal; Chicago No 2 corn; Poultry fats: 0.19 cents/ lb. LEP = Live weight equivalent price, derived from Ready to Cook (RTC) prices using the following formula = [RTC price - processing cost] x dressing percentage (0.774)] = (RTC-0.319)*0.774

Table 8: Profits for cut up parts and body weight using simulations and non linear programming

	Body weight and cut up parts									
	Dynamic model BW				Dynamic model CW					
		bBW		aBW	DP	CW	BM	T	D	W
DND	rBW	kg	tBW	kg	%	kg				
Simulation of the calculated equations										
3.000	0.951	3.27	0.99	2.973	77.1	2.293	0.53	0.37	0.32	0.25
3.050	0.968	3.27	0.99	3.027	77.6	2.350	0.54	0.38	0.33	0.26
3.100	0.982	3.27	0.99	3.070	78.0	2.393	0.55	0.39	0.34	0.27
3.125	0.988	3.27	0.99	3.088	78.0	2.410	0.55	0.39	0.34	0.27
3.150	0.993	3.27	0.99	3.103	78.1	2.423	0.56	0.39	0.34	0.27
3.175	0.997	3.27	0.99	3.115	78.1	2.433	0.56	0.40	0.34	0.27
3.200	1.000	3.27	0.99	3.125	78.1	2.439	0.56	0.40	0.34	0.27
3.250	1.003	3.27	0.99	3.136	77.8	2.442	0.56	0.40	0.34	0.27
3.300	1.004	3.27	0.99	3.137	77.4	2.430	0.56	0.40	0.34	0.27
3.350	1.000	3.27	0.99	3.128	76.9	2.404	0.55	0.39	0.34	0.27
Maximum profit feed formulation using the non linear programming										
3.169[a]	0.996	3.27	0.99	3.113	78.1	2.431	0.56	0.40	0.34	0.27
3.177[b]	0.997	3.27	0.99	3.116	78.1	2.434	0.56	0.40	0.34	0.27

	Income total $/bird		Feed intake				Cost of diet $/bird		Cost total $/bird		Profitability $/bird	
DND	CW	BW	rFC	bFC kg	tFC	aFC kg	CW	BW	CW	BW	CW	BW
Simulation of the calculated equations												
3.000	3.161	3.255	0.99	6.7	0.99	6.55	0.187	0.187	2.40	1.67	0.7569	1.584
3.050	3.239	3.314	1.00	6.7	0.99	6.59	0.191	0.191	2.44	1.71	0.7998	1.608
3.100	3.299	3.362	1.00	6.7	0.99	6.62	0.195	0.195	2.47	1.74	0.8280	1.624
3.125	3.322	3.381	1.00	6.7	0.99	6.62	0.197	0.197	2.49	1.75	0.8364	1.629
3.150	3.340	3.398	1.00	6.7	0.99	6.62	0.199	0.199	2.50	1.77	0.8412	1.6315
3.175	3.354	3.411	1.00	6.7	0.99	6.61	0.201	0.201	2.51	1.78	0.8421	1.6326
3.200	3.363	3.422	1.00	6.7	0.99	6.60	0.204	0.204	2.52	1.79	0.8394	1.6318
3.250	3.366	3.435	0.99	6.7	0.99	6.56	0.208	0.208	2.54	1.81	0.8227	1.625
3.300	3.349	3.435	0.99	6.7	0.99	6.51	0.262	0.262	2.89	2.15	0.4634	1.282
3.350	3.314	3.425	0.97	6.7	0.99	6.43	0.332	0.401	3.31	3.03	0.0000	0.397
Maximum profit feed formulation using the non linear programming												
3.169[a]	3.351	3.408	1.00	6.7	0.99	6.61	0.201	0.201	2.51	1.78	0.8423	1.6325
3.177[b]	3.355	3.412	1.00	6.7	0.99	6.61	0.202	0.202	2.51	1.78	0.8422	1.6327

Diet = 3.145 Price of corn and SBM USDA, 0.1508, 0.2053 $/kg respectively. Poultry oil = 0.19 $/lb, For the dynamic model CW 0.447 and 0.733 $/bird were included in the total cost from cost of live and process carcass respectively and for dynamic model BW only 0.447 $/bird from cost of live. Temperature 21°C, broiler livability 96% and prices of product from the month of March, 2007.
[a]Formulated with MPFF and cup up model as objective. [b]Formulated with MPFF and body weight model as objective

the model of Gonzalez-Alcorta *et al.* (1994); as the price of soybean meal increased, the protein level decreased and the energy level increased. However, this decreased nutrient content can be different when two protein ingredients are offered in the formulation. In the present study, soybean meal was the primary source of protein. Likewise as the price of poultry fat increased, the DND tended to decrease markedly; the levels of poultry fat and soybean meal were decreased, whereas the levels of corn were increased. In the comparison of profitability

Table 9: Variations of livability, temperature, process cost and price for broilers, corn and soybean meal

	Feed ingredients				Carcass	Feed	Diet cost		Profit margin			
	-----------------%---------------			DND	weight	intake	--------$/Kg--------		--------$/bird-------			Yearly
Variables	Corn	SBM	P. Fat	Kcal/g	Kg	Kg	MPFF	LPFF	MPFF	LPFF	Differ.	Profit $
Livability, %												
100	54.68	35.76	5.45	3.172	2.533	6.612	0.2012	0.1989	0.9820	0.9796	0.0023	152,119
98	54.75	35.72	5.41	3.171	2.482	6.613	0.2011	0.1989	0.9121	0.9101	0.0020	131,668
96	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.8423	0.8406	0.0017	112,258
94	54.92	35.64	5.32	3.167	2.380	6.614	0.2008	0.1989	0.7725	0.7710	0.0014	93,974
Temperature, °C												
21	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.8423	0.8406	0.0017	112,258
23	54.78	35.71	5.39	3.170	2.429	6.521	0.2010	0.1989	0.8573	0.8555	0.00189	122,580
25	54.76	35.72	5.41	3.171	2.367	6.310	0.2011	0.1989	0.8141	0.8122	0.00192	125,043
27	54.76	35.72	5.41	3.171	2.245	5.979	0.2011	0.1989	0.7127	0.7108	0.00184	119,326
29	54.78	35.71	5.40	3.170	2.064	5.530	0.2010	0.1989	0.5529	0.5513	0.00162	105,395
Process cost ($/bird), 0.733												
P. cost (25%+)	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.659	0.657	0.00173	112,258
P. cost (50%+)	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.476	0.474	0.00173	112,258
P. cost (75%+)	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.293	0.291	0.00173	112,258
Prices changes, $/kg												
Standard	54.84	35.68	5.37	3.169	2.431	6.613	0.2009	0.1989	0.8423	0.8406	0.0017	112,258
Broiler (25% -)	56.33	34.98	4.60	3.139	2.418	6.619	0.1985	0.1989	0.006	0.006	0.0001	4,542
Broiler (25%+)	54.06	36.05	5.76	3.184	2.436	6.608	0.2022	0.1989	1.681	1.675	0.0062	400,088
Broiler(50%+)	53.59	36.27	6.00	3.194	2.438	6.603	0.2030	0.1989	2.521	2.509	0.0117	763,044
Corn (50% -)	56.92	34.71	4.30	3.127	2.412	6.619	0.1546	0.1567	1.121	1.120	0.0010	63,236
Corn (25%-)	55.91	35.18	4.82	3.148	2.422	6.618	0.1781	0.1778	0.980	0.980	0.0000	1,432
Corn (25%+)	49.06	40.34	6.69	3.190	2.437	6.605	0.2221	0.2192	0.713	0.707	0.0060	386,979
Corn (50%+)	43.02	40.91	9.00	3.192	2.437	6.604	0.2393	0.2362	0.600	0.594	0.0064	418,284
SBM (50% -)	32.08	55.32	9.00	3.172	2.432	6.612	0.1579	0.1558	1.128	1.126	0.0024	153,933
SBM (25% -)	49.54	40.15	6.42	3.179	2.434	6.610	0.1821	0.1797	0.972	0.968	0.0036	234,819
SBM (25%+)	55.47	35.39	5.04	3.156	2.426	6.616	0.2180	0.2170	0.722	0.721	0.0004	24,309
SBM (50%+)	56.14	35.07	4.70	3.143	2.420	6.618	0.2348	0.2350	0.602	0.602	0.0000	766
SBM (75%+)	56.85	34.74	4.34	3.129	2.412	6.619	0.2511	0.2530	0.483	0.483	0.0007	46,611
SBM (100%+)	57.58	34.40	3.96	3.114	2.403	6.618	0.2670	0.2710	0.366	0.363	0.0026	167,198
SBM (125%+)	58.36	34.03	3.57	3.099	2.393	6.615	0.2824	0.2891	0.250	0.244	0.0057	368,266
SBM (150%+)	59.17	33.65	3.15	3.083	2.380	6.610	0.2974	0.3071	0.135	0.125	0.0101	655,963
P. fat (50%-)	43.29	41.06	9.00	3.205	2.440	6.597	0.1886	0.1857	0.939	0.928	0.0112	726,663
P. fat (25%-)	53.38	36.36	6.11	3.198	2.439	6.601	0.1969	0.1940	0.882	0.873	0.0085	552,446
P. fat (25%+)	56.32	34.99	4.61	3.139	2.418	6.619	0.2033	0.2039	0.808	0.808	0.0001	5,868
P fat (50%+)	57.81	34.29	3.85	3.110	2.400	6.617	0.2041	0.2089	0.778	0.775	0.0037	240,900
P. fat (75%+)	59.32	33.59	3.08	3.080	2.377	6.608	0.2032	0.2139	0.754	0.742	0.0126	822,062
P. fat (100%+)	60.82	32.88	2.31	3.050	2.350	6.593	0.2007	0.2188	0.736	0.709	0.0269	1,750,984
P. fat (125%+)	62.32	32.18	1.55	3.020	2.318	6.570	0.1967	0.2238	0.722	0.676	0.0466	3,026,168
P. fat (150%+)	63.80	31.49	0.80	2.990	2.281	6.541	0.1911	0.2288	0.714	0.643	0.0714	4,643,055

Standard prices: Prices for corn, soybean meal and fat were 150.78, 205.26 and 418.88 $/tons respectively; Cut up parts price = 1.38 $/kg = [(3.362x0.23+1.247x0.163+1.247*0.141+1.68x0.111) x 0.9 + 1.734x0.1], where: Whole bird price = 1.734, Breast = 3.362; Thighs = 1.247; Leg = 1.247; Wing = 1.68; $/kg. Standard characteristics: Livability=96%; Temperature=21°C; Process cost=0.4437 $ per broiler. LCFF (least cost feed formulation) = fixed ME = 3.145kcal/g; CW = 2.4209kg; FC = 6.618 kg. Cost for live bird (without feed) $/bird = 0.447 and process cost, $/bird = 0.733. Assuming a typical broiler complex slaughtering 1250000 broilers per week. DND (dietary nutrient density)= [3.023-3.383], Differ. =Difference between MPFF and LCFF. MPFF=maximum profit feed formulation. LCFF=least cost feed formulation

between MPFF and LCFF, the best profit difference was found when poultry oil price increased by 150%.

Comparing maximum profit feed formulation of the dynamic model CW with LCFF model using the two broiler prices, the difference in profit was $ 76,454 for starting prices and $150, 938 for ending prices in the evaluated period (Table 10). As expected, the ending prices used in the model produced better profitability than those of starting prices since the former price is the real price. The MPFF using the starting prices was better in profits than those of LCFF and had a similar pattern in profits as did ending prices. In periods where ending prices had the highest profits, the starting prices also had the highest profits. Though LCFF was superior for only two periods of formulation, the MPFF using the starting prices was better for ten periods of formulation. When the prices of corn, soybean meal and broiler meat tended to increase, the two models, dynamic Model BW and dynamic model CW increased the DND, whereas the LCFF model kept a constant DND (3.145 ME kcal/g) in the evaluated period. The two dynamic models showed differences in the estimation of DND; the dynamic model CW estimated a narrower range of DND compared with those of dynamic model BW (Table 11). The diets formulated using the dynamic models were more profitable than those of the LCFF model. For example, the differences of profitability for dynamic model BW and CW compared to LCFF were $341,177

Table 10: Comparisons of profitability of MPFF and LCFF using the start and end prices of broiler meats

	Start prices						
		had been Formulated	Ingredients				
Months	Price $/kg	DND Kcal/g	Corn	SBM	Fat	Carcass weight Kg	Feed intake Kg
			-----	%	-----		
Mar	0.928	3.078	59.40	33.55	3.04	2.376	6.608
Apr	0.904	3.077	59.44	33.53	3.02	2.375	6.607
May	1.029	3.105	58.06	34.17	3.72	2.397	6.616
Jun	1.141	3.118	57.40	34.49	4.06	2.406	6.618
Jul	1.176	3.126	56.98	34.68	4.27	2.411	6.619
Aug	1.218	3.128	56.92	34.71	4.30	2.412	6.619
Sep	1.174	3.118	57.41	34.48	4.05	2.406	6.618
Oct	1.005	3.113	57.65	34.37	3.93	2.403	6.618
Nov	0.973	3.121	57.23	34.56	4.14	2.408	6.619
Dec	1.100	3.145	56.04	35.12	4.75	2.421	6.618
Jan	1.197	3.156	55.47	35.39	5.04	2.426	6.616
Feb	1.316	3.166	54.98	35.62	5.29	2.430	6.614
Total (yearly)							

End prices			Profit Margin			Monthly Profit difference	
		should be formulated	MPFF				
Months	Price $/Kg	DND Kcal/g	Start price	End price	LCFF	Start price	End price
			-----	$/bird	-----		
May	1.029	3.097	0.3264	0.3272	0.3221	23,445	27,895
Jun	1.141	3.117	0.5715	0.5755	0.5736	-11,292	10,629
Jul	1.176	3.125	0.6350	0.6361	0.6350	351	5,938
Aug	1.218	3.127	0.7437	0.7440	0.7431	3,635	4,823
Sep	1.174	3.126	0.6472	0.6472	0.6462	5,100	5,100
Oct	1.005	3.099	0.2990	0.3007	0.2961	15,363	24,896
Nov	0.973	3.087	0.2156	0.2175	0.2105	27,329	37,804
Dec	1.100	3.126	0.3835	0.3839	0.3831	2,177	4,454
Jan	1.197	3.148	0.5015	0.5034	0.5033	-10,007	147
Feb	1.316	3.163	0.7959	0.7969	0.7959	0	5,194
Mar	1.378	3.169	0.8979	0.8984	0.8966	6,916	9,551
April	1.452	3.174	1.0002	1.0004	0.9977	13,435	14,508
Total (Yearly)						76,454	150,938

Note: The profit margins of start price, end price and LCFF diets were calculated from the end broiler prices for comparison purpose.
LCFF = fixed ME = 3.145 kcal/g; CW = 2.4209 kg; FC = 6.618 kg and Feed Formulation: Corn = 56.04%, SBM = 35.12% and Poultry oil = 4.75%, Livability = 96%; Temperature = 21 C; Cost of live = 0.447 $/bird; Process cost = 0.733 $/bird, Assuming a typical broiler complex slaughtering 1,250,000 birds/week or 5,416,667 birds/month or 65,000,000 birds/year, Monthly profit difference for start price = 1,250,000*52/12* (MPFF start price-LCFF). Yearly profit difference for end price = 1,250,000*52/12* (MPFF end price-LCFF). Total (yearly) = the sum of monthly profit differences from March to February

and $132,424 per year respectively, assuming a typical broiler complex slaughtering 1,250,000 broilers per week or 65,000,000 broilers per year. In the months in which the DND were far from the static nutrient requirements of 3.145 ME kcal/kg, diets from dynamic models were the more profitable. This is why the dynamic model CW had the lower difference in profitability compared to the dynamic model BW.

The estimation of the DND for each phase is presented in the Table 12; the DND for each phase was transformed back from the mean of DND produced by the model. We can see the differences of DND for each phase based on previous feeding phase. With this new model we can recommend different feeding programs because the energy and protein levels tend to increase and decrease, respectively, as the bird aged. Further after the MPFF calculated the mean of DND, the specific DND for each phase should be formulated with least cost feed formulation. This means that MPFF can be used before the LCFF to recommend specific DND or dynamic nutrient requirements to increase the profitability.

Fisher and Wilson (1974) found that sex, age and breed affect the rate of response to dietary metabolizable energy; whereas, diet form (pellet and mash) and environmental factors did not affect it. Hence, this new

Table 11: Variations of ingredient costs and broiler prices and comparisons of dynamic model CW and BW

	Feed ingredients						-------DND------		Body	Carcass	Feed intake	
	------------- BW ---------------			--------------- CW --------------			[3000-3.383]		weight	weight		
	Corn	SBM	Fat	Corn	SBM	Fat	BW	CW	BW	CW	BW	CW
Time	-------------------------------%---						------Kcal/g-------		----------------------Kg----------------------			
April	62.20	32.24	1.61	59.44	33.53	3.02	3.022	3.077	3.00	2.38	6.572	6.607
May	61.65	32.50	1.89	58.06	34.17	3.72	3.033	3.105	3.01	2.40	6.581	6.616
Jun	60.20	33.17	2.63	57.40	34.49	4.06	3.062	3.118	3.04	2.41	6.600	6.618
Jul	59.04	33.72	3.22	56.98	34.68	4.27	3.085	3.126	3.06	2.41	6.611	6.619
Aug	59.02	33.73	3.23	56.92	34.71	4.30	3.086	3.128	3.06	2.41	6.611	6.619
Sept	59.50	33.50	2.99	57.41	34.48	4.05	3.076	3.118	3.05	2.41	6.607	6.618
Oct	58.77	33.84	3.36	57.65	34.37	3.93	3.091	3.113	3.06	2.40	6.612	6.618
Nov	57.49	34.44	4.01	57.23	34.56	4.14	3.116	3.121	3.08	2.41	6.618	6.619
Dec	56.69	34.82	4.42	56.04	35.12	4.75	3.132	3.145	3.09	2.42	6.619	6.618
Jan	55.67	35.29	4.94	55.47	35.39	5.04	3.152	3.156	3.10	2.43	6.617	6.616
Feb	54.71	35.74	5.43	54.98	35.62	5.29	3.172	3.166	3.11	2.43	6.612	6.614
Mar	54.45	35.87	5.56	54.84	35.68	5.37	3.177	3.169	3.12	2.43	6.611	6.613
Apr- Mar												

	Diet Cost				Profit Margin					
	---------- BW ---------		-------- CW ---------		---------- BW ----------		--------- CW ----------			
	MPFF	LCFF	MPFF	LCFF	MPFF	LCFF	MPFF	LCFF	BW	CW
Time	-------------------------$/Kg-----------------------				---------------------------$/bird-----------------------				--- Profit difference ---	
April	0.139	0.152	0.145	0.152	0.912	0.895	0.009	0.000	90125	47137
May	0.144	0.156	0.152	0.156	0.921	0.907	0.283	0.280	74607	19522
Jun	0.146	0.155	0.152	0.155	1.179	1.170	0.558	0.556	46960	9967
Jul	0.147	0.153	0.151	0.153	1.327	1.322	0.653	0.652	26006	4965
Aug	0.138	0.145	0.143	0.145	1.447	1.442	0.813	0.812	27126	4577
Sep	0.138	0.146	0.143	0.146	1.436	1.429	0.698	0.696	36533	10677
Oct	0.161	0.166	0.163	0.166	1.138	1.134	0.155	0.152	19528	11662
Nov	0.181	0.184	0.182	0.184	1.061	1.060	-0.039	-0.040	5192	5975
Dec	0.182	0.183	0.183	0.183	1.094	1.094	0.273	0.273	1055	0
Jan	0.191	0.190	0.191	0.190	1.253	1.253	0.459	0.458	381	1799
Feb	0.204	0.202	0.204	0.202	1.467	1.466	0.671	0.670	5376	6790
Mar	0.202	0.199	0.201	0.199	1.634	1.632	0.842	0.841	8287	9355
Apr-Mar								341177	132424	

Corn, soybean meal and broiler prices for each month were obtained from Table 7. Profit (BW) = [(BW x live weight equivalent)-(FI x diet cost + cost of live bird (0.447$/bird))]; Profit CW = [(CWxPrice of wholesale of Cup up parts) -(FI x diet cost + cost of live bird (0.447) +process cost(0.733))]. Profit margin difference for BW = MPFF of BW-LCFF of BW. Profit margin difference for CW = MPFF of CW-LCFF of CW

Table 12: Recommended DND (kcal/g) for each phase for the two dynamic models from the mean of DND obtained by variations of ingredients costs and broiler prices (output of Table 11)

	Dynamic Model: BW				Dynamic Model: CW			
	[3.023-3.383] DND	Starter	Grower	Finisher	[3.023-3.383] DND	Starter	Grower	Finisher
		-----------------------ME------------------------				----------------------ME----------------------		
Time	---Kcal/g---							
April	3.022	2.987	3.027	3.078	3.077	3.041	3.082	3.134
May	3.033	2.998	3.038	3.089	3.105	3.068	3.109	3.161
Jun	3.062	3.026	3.067	3.118	3.118	3.081	3.122	3.175
Jul	3.085	3.049	3.090	3.142	3.126	3.089	3.130	3.183
Aug	3.086	3.049	3.090	3.142	3.128	3.090	3.132	3.184
Sept	3.076	3.040	3.081	3.133	3.118	3.080	3.122	3.175
Oct	3.091	3.054	3.095	3.147	3.113	3.076	3.117	3.170
Nov	3.116	3.079	3.120	3.173	3.121	3.084	3.125	3.178
Dec	3.132	3.094	3.136	3.189	3.145	3.107	3.149	3.202
Jan	3.152	3.114	3.156	3.210	3.156	3.118	3.160	3.214
Feb	3.172	3.133	3.175	3.229	3.166	3.128	3.170	3.223
Mar	3.177	3.138	3.180	3.234	3.169	3.130	3.173	3.226

DND: obtained from maximum profit feed formulation from two dynamic models, BW and CW. ME: obtained from linear regression: ME starter = 0.97532xDND + 0.03962; ME grower = 0.99079xDND + 0.03292; ME finisher = 1.00991xDND + 0.02593. These linear regressions were obtained from data of Saleh *et al.* (2004) between ME of each phase and average DND model is recommended for Ross male lines with the static nutritional requirement and ingredients used; however, for other sex or commercial broiler lines, static nutritional requirements from industry standards and ingredients should be quantified by dose-response approach before be used in the maximum profit feed formulation. The nutrient requirements formulated by Saleh *et al.* (2004) were not used as static nutrient requirement in the present study because they did not reflect practical diet costs. However, these new nutrient: energy ratios of the model can produce a different dose-response from those of Saleh *et al.* (2004).

Conclusions: Livability affected the DND only slightly, whereas environmental temperature and processing costs had little effect on DND. When corn and broiler prices increased, the DND also increased. In contrast, when soybean meal and poultry oil prices increased, the DND tended to decrease. Starting broiler prices had a similar pattern in profits as the ending broiler prices, producing the former price a higher profit than did the Least Cost Feed Formulation (LCFF). The diets formulated using the Maximum Profit Feed Formulation (MPFF) showed differences in DND between the dynamic model CW and BW. For all the variables used, MPFF was superior in economic terms to the conventional LCFF. This new model of formulation can be used to complement least cost formulation in order to get the best profitability.

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[2]To whom correspondence should be addressed. Waldroup@uark.edu.