Using the Matrix Algebra Capabilities of the TI59 Calculator for Teaching Ration Formulation[1]

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ABSTRACT Procedures are illustrated for using the matrix algebra capabilities of the TI59 calculator to rapidly and accurately calculate rations involving several requirements and ingredients. A broiler ration example is given in which requirements for energy, protein, calcium, and available phosphorus are met by corn, soybean meal, tallow, mono-dicalcium phosphate, limestone, and fixed ingredients.

(*Key words:* ration formulation, teaching aid, research aid, programmable calculator)

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INTRODUCTION

Pearson's Square and the solution of simultaneous equations by linear combinations are commonly used to teach the hand calculation of rations. Although these procedures can be used to formulate for two or more requirements (Church, 1978; Schiable, 1979), the methods can become mathematically cumbersome.

Simultaneous equations can be solved by matrix algebra. Selvarajah *et al.* (1969) and Ensminger (1980) have illustrated the value of using matrix algebra in formulating rations. However, the ability to perform matrix inversion has been a limiting step. The development of matrix programs for programmable calculators now offers a readily accessible source for matrix procedures.

The following is an example of how the TI59 programmable calculator with matrix algebra capabilities can simplify the formulation of a ration involving several requirements and ingredients.

EXAMPLE AND DISCUSSION

Requirements. To illustrate the procedure, a broiler starter ration was proposed with five requirements and five variable ingredients. The nutritional requirements were based on National Research Council (NRC, 1977) recommendations. The five requirements for the broiler ration were 3200 kcal/kg metabolizable energy (ME), 23% protein, .9% calcium, .5% available phosphorus and with the ration totaling to 100%. The second step was to determine the fixed ingredients to be included in the ration. Table 1 indicates the requirements, the fixed ingredients, the contribution made by the fixed ingredients toward the requirements, and the amount to be provided by the variable ingredients. In this example, it was decided that the variable ingredients would include corn (C), soybean meal (SBM), tallow (T), monodicalcium phosphate (MDP) and limestone flour (L).

The setup of the linear and matrix equations for the broiler ration example is shown in Table 2. Coefficients of the ingredients in the simultaneous equation and the elements of the nutrient matrix are in decimal form. In the case of energy, the kilocalories per kilogram of ME for each ingredient are divided by 100. The figures on the right side of the simultaneous equation and the elements of the requirement matrix are in percentage form. Again exception is made for energy, which is the ME requirement adjusted for the fixed ingredients.

Solution by Matrices. The following set of linear equations such as those used in ration formulation:

$$
\begin{array}{l}
a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = b_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n = b_2 \\
\quad\vdots \\
a_{n1}x_1 + a_{n2}x_2 + \ldots + a_{nn}x_n = b_n
\end{array}
$$

can be written as the matrix equation:

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TABLE 1. *Adjustment of requirements for broiler ration example*

Requirement	Amount required[a]	Amount provided by fixed ingredients[b]	Amount required from variable ingredients[c,d]
Energy (kcal/kg ME)	3200	282	2918
Protein (%)	23.00	4.64	18.36
Calcium (%)	.90	.18	.72
Phosphorus, available (%)	.50	.10	.40
Total (%)	100.00	11.40	88.60

[a]National Research Council (1977).

[b]Fixed ingredients included corn gluten meal, 3.0%; fish meal, 2.5%; corn dried distillers grains with solubles, 2.5%; alfalfa meal, 2.5%; salt, .25%; DL-methionine, .15%; and a vitamin-trace mineral mix, .5%.

[c]These requirement values, which have been adjusted for the contribution of fixed ingredients, make up matrix B.

[d]Variable ingredients included corn, soybean meal (49.3%), tallow, monodicalcium phosphate, and limestone flour.

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ \cdot \\ \cdot \\ \cdot \\ b_n \end{bmatrix}$$

A more concise notation for this last equation would be AX = B, where A is a n × n square matrix, and X and B are n × 1 column matrices. The X matrix can be solved for by multiplying both sides of the equation by A^{-1} to obtain:

$$A^{-1}AX = A^{-1}B,$$
$$IX = A^{-1}B,$$
$$X = A^{-1}B,$$

where $A^{-1}B$ is a n × 1 column matrix and I is an identity matrix. Because X and $A^{-1}B$ are equal, each entry in X is equal to the corresponding entry in $A^{-1}B$, and hence, these latter entries constitute the components to the solution of the linear system (Breckenbach and Brooyan, 1968). In calculation of rations, A represents the nutrient matrix, B the requirement matrix, and X the ingredient matrix.

Calculator Procedure. Table 3 shows the steps for solving the problem on a TI59 calculator. First the matrix program (02) was chosen from the master library, the order of the matrix entered, the nutrient matrix (A) entered, the determinant calculated, the requirement matrix (B) entered, and the ingredient matrix (X) calculated and displayed.

The resulting answer for the broiler ration example included 50.77% corn; 28.64% soybean meal; 6.77% tallow; 1.45% monodicalcium phosphate, and .96% limestone. When the contributions made by the fixed ingredients were added to the variable ingredient totals, the resulting energy (3199.52 kcal/kg ME), protein (23%), calcium (.9%), available phosphorus (.5%), and ration total (99.99%) values, when rounded off, met the requested requirements. If new requirements are desired, they can be solved for by repeating steps 5 through 7.

The TI59 calculator has the capability of solving an 8 × 8 simultaneous equation by matrix algebra. However, the calculator data registers must be repartitioned for matrices larger than 5 × 5. A more in-depth discussion of the matrix procedures for the programmable calculator can be found in the calculator manual (Texas Instruments, Inc., 1977).

It should be noted that the nutrient matrix must be a square matrix. That is, the number of requirements must equal the number of ingredients. Also, when calculated the determinant of the nutrient matrix must not equal zero. If it does, then a dependency of a row or column on another row or column is indicated. Therefore, an adjustment must be made in one or more of the nutrients in the matrix. The answer in the solution may contain negative numbers for some of the ingredients. This indicates that a change in one or more of the ingredients or requirements must be made so that a feasible solution can be obtained. For example, a low energy ration may be desired with high energy ingredients such as animal fat or corn entered in the matrices. It may be necessary to substitute

TABLE 2. *Set-up of equations for broiler ration example*

Simultaneous equation form[a]

.088 C +	.485 SBM +	0 T +	0 MDP +	0 L	= 18.36	(Protein
34.30 C +	24.40 SBM +	70.50 T +	0 MDP +	0 L	= 2918	(Energy)
.0002 C +	.0027 SBM +	0 T +	.185 MDP +	.380 L	= .720	(Calcium)
.0008 C +	.0019 SBM +	0 T +	.210 MDP +	0 L	= .400	(Phosphorus)
1.000 C +	1.000 SBM +	1.000 T +	1.000 MDP +	1.000 L	= 88.60	(Total)

Matrix algebra form[a]

$$\begin{bmatrix} .088 & .485 & 0 & 0 & 0 \\ 34.30 & 24.40 & 70.50 & 0 & 0 \\ .0002 & .0027 & 0 & .185 & .380 \\ .0008 & .0019 & 0 & .210 & 0 \\ 1.000 & 1.000 & 1.000 & 1.000 & 1.000 \end{bmatrix} \begin{bmatrix} C \\ SBM \\ T \\ MDP \\ L \end{bmatrix} = \begin{bmatrix} 18.36 \\ 2918 \\ .720 \\ .400 \\ 88.60 \end{bmatrix} \begin{matrix} \text{(Protein)} \\ \text{(Energy)} \\ \text{(Calcium)} \\ \text{(Phosphorus)} \\ \text{(Total)} \end{matrix}$$

[a]C, corn; SBM, soybean meal; T, tallow; MDP, monodicalcium phosphate; L, limestone flour.

TABLE 3. *TI59 programmable calculator procedure for broiler ration example*

STEP	ENTER	PRESS	DISPLAY	COMMENTS	PRINTOUT
1		2nd pgm 02		Select program	
2	5	A	5	Enter order of matrix	5
3	1	B	1	Start with column 1	
	.088	R/S	.088	a_{11}	.088
	34.30	R/S	34.30	a_{21}	34.30
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	1.0	R/S	1.0	a_{51}	1.0
	.485	R/S	.485	a_{12}	.485
	24.40	R/S	24.40	a_{22}	24.40
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	1.0	R/S	1.0	a_{55}	1.0
4		C	−1.076362095	If $\|A\| \neq 0$:Continue	−1.076362095
5	1	D	1	Start with b_1	1
	18.36	R/S	18.36	b_1	18.36
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	88.6	R/S	88.6	b_5	88.6
6		CLR E	1	Calculate X	
7	1	2nd A'	1	Start with X_1	
		R/S	50.77227692	X_1 (% Corn)	50.77227692
		R/S	28.64338068	X_2 (% Soybean meal)	28.64338068
		R/S	6.774644157	X_3 (% Tallow)	6.774644157
		R/S	1.45218931	X_4 (% Mono-dical. Phos.)	1.45218931
		R/S	.9575089325	X_5 (% Limestone)	.9575089325
8	To solve the system for a new set of requirements (b') repeat steps 5 through 7.				

a low energy ingredient or filler for the animal fat or corn in order to calculate a feasible ration.

The use of the matrix procedure available on the TI59 programmable calculator offers a rapid and precise method for the teaching of hand calculated rations involving several requirements and ingredients.

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