SOME ECONOMIC ASPECTS OF STOCKING RATE AND FEEDER SPACE ALLOCATION IN BROILER PRODUCTION

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This paper reports the results of economic analysis of the effects of floor space and feeder space on broiler chicken growth rates. First, liveweight/feed conversion rates are described and a function fitted. Use of conversion efficiency functions for determining optimal space inputs in the production process would be appropriate where feed cost considerations are dominant. Second, use of more orthodox response surface analysis permits specific consideration of marginal productivities of floor and feeder space inputs. Optimal input levels (i.e., stocking rates and feeder space allocations) and profit margins are developed parametrically for a range of input costs and liveweight prices.

1 INTRODUCTION

With the continuing expansion of the broiler industry there is an increasing need for quantitative data relating to the effects of on-farm management practices in the broiler-growing process. To this end the University of New England is conducting a series of broiler production trials at the Laureldale poultry research facility, one purpose of which is to examine selected management variables which are believed to be important in themselves, and necessary components of any more general economic model of the broiler-growing process.

Because of physical research limitations and the need to approximate near-commercial conditions, only a limited number of variables can be examined simultaneously. This paper presents the results of an analysis of stocking rate and feeder-space allocations for broilers on deep litter. Physical effects of these factors on liveweight are examined, first in relation to the feed/meat conversion ratio criterion which is conventional in the industry, and then within the framework of production economics analysis.

In general, variation in shed space per bird on broiler farms has the same economic implications as stocking-rate adjustments have in a grazing system: it represents a management potential to increase returns to an expensive fixed factor, here sheds and ancillary equipment.

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Actual stocking rates on broiler farms vary considerably, but the trend is to higher rates, and possibly one square foot per bird is the modal rate among New South Wales growers—a rather rough management rule of thumb. The factors preventing very high-density broiler growing are many and complex, but "stress" due to reduced or limited access to feed as shed population increases is certainly important. Among the other measures available to management is an increase in the number of feeders relative to floor space, and/or use of a higher quality ration. The first of these measures is evaluated in the present trial.

The economic objectives of the trial reported here were to generate data which would permit:

(i) an estimation of the physical production function relating shed space and feeder space to liveweight;

(ii) determination of the effects of variations in shed and feeder space in terms of feed/liveweight conversion ratios;

(iii) derivation of relationships represented by response surface, marginal quantities and isoquants;

(iv) determination of profit-maximizing shed and feeder space input levels under a range of price situations.

2 TRIAL DESIGN

The trial was conducted in a shed designed to approximately duplicate conditions in most commercial broiler houses: necessary modifications were a concrete slab floor and internal division of the shed into 32 pens, each 8 x 10 feet, with wire mesh partitions. Day-old commercial strain chicks were used. These were raised to 4 weeks of age under uniform management and feed conditions. At 4 weeks of age birds were randomly assigned among 32 pens at 4 stocking rates. Feeder space allocation in each pen was made by varying the number of standard commercial hang-type cylinder feeders, each of 47-inch feeding circumference.

The 16 treatment combinations were applied in a randomized block design. The number of replications was limited to 2 by the capacity of trial facilities. It is assumed all birds had equal feeding opportunity within the limits set by each treatment, and that effects in terms of feed consumption, weight gain and conversion ratio are an aggregative measure of "stress" effects. Nominal feeder space in inches per bird for each treatment is obtained as: number of feeders x 47/number of birds per pen. Starting at the end of the 5th week, then at regular weekly intervals, all birds were weighed and weekly feed consumption recorded until completion of the trial at the end of the 11th week. The treatments in terms of floor- and feeder-space combinations used, and liveweight achieved and cumulative feed consumption at the end of the trial are shown in the Appendix.

3 CONVERSION RATIOS

The effects of varying stocking rate and feeder-space can be examined directly in terms of conversion ratios, or in terms of marginal (liveweight)

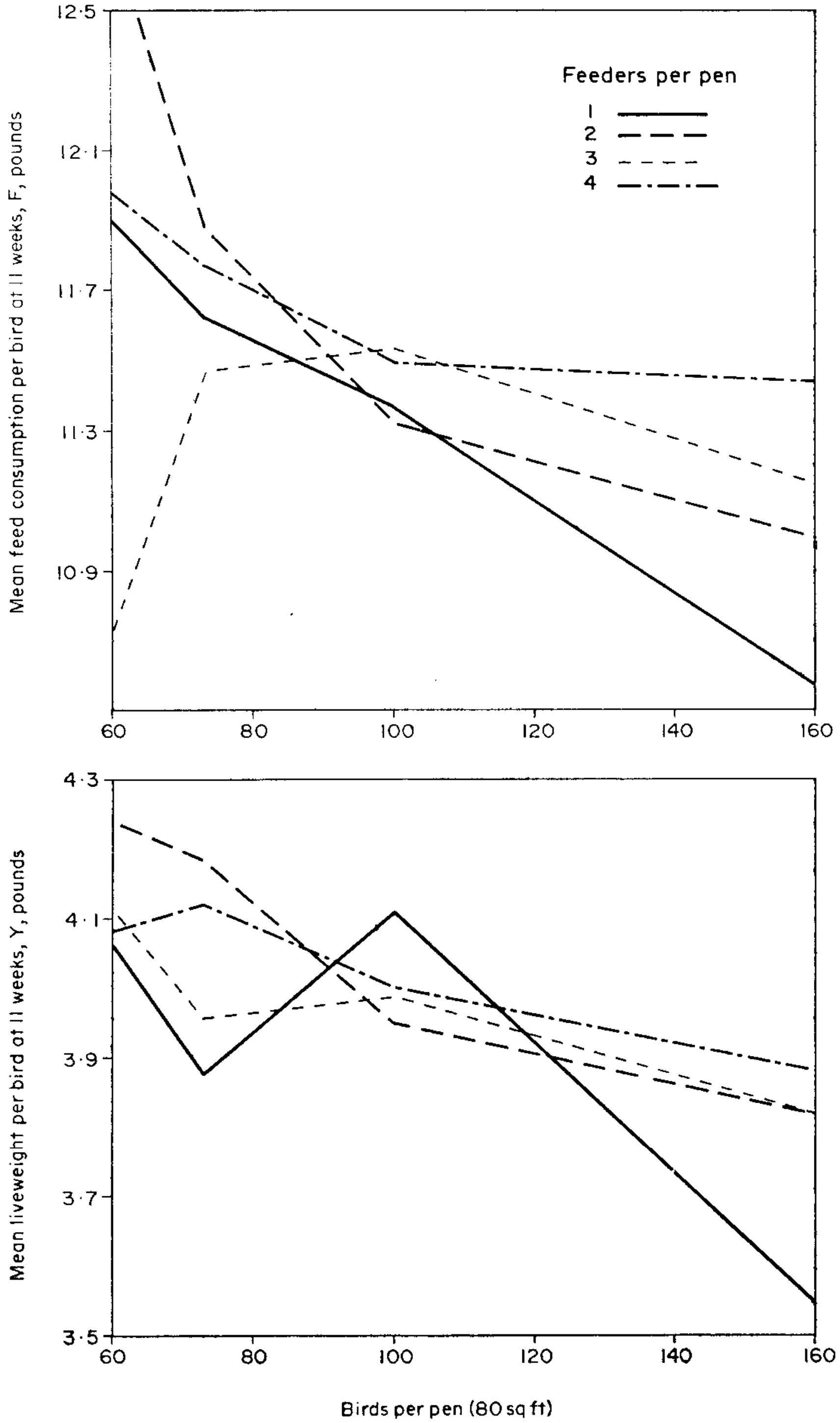

FIGURE 1

Mean Liveweight and Cumulative Feed Consumption at 11 *weeks for Four Stocking Rates and Feeder Numbers* (*means of* 2 *replications each treatment*) productivities of the shed and feeder space factors. The first of these is examined in this section.

It is usual in the broiler industry to evaluate trial results in terms of pounds of feed required per pound of liveweight produced, or simply, the "conversion ratio". This is at least a handy criterion, if not always a strictly relevant one, and it reflects the dominance of feed in costs of production—something in the order of 67 to 75 per cent of total costs on a typical farm.

Figure 1 summarizes the results of the 16 discrete treatment levels used in the trial in terms of mean feed consumption and mean liveweight achieved per bird at the end of 11 weeks. For all feeder space levels (i.e. K values) feed consumption, in general, decreases with increased stocking rate. Similarly, mean per bird terminal liveweight decreases at higher stocking rates.

Of the feeder-space treatment levels applied, no apparent effect on feed consumption is evident until shed density reaches about 110 birds, a stocking rate of approximately 0·73 square feet per bird. At the highest stocking rate of 80/160 or 0·5 square feet per bird, figure 1 shows that feed consumption is affected by feeder-space. Maximum consumption is achieved with the equivalent of 3 or more feeders per 80 square feet.

As with feed consumption, no clear relationship between feeder space and stocking rate emerges until stocking rate has increased past about 120 birds, or approximately 0·67 square feet per bird. At the highest stocking rate an apparently significant relationship exists between feeder space and liveweight. Obviously a relationship exists between feed consumption, F, and liveweight, Y, and less obviously between F/Y (or Y/F) and the two management variables, feeder space K, and stocking rate S. The reciprocal of the conventional conversion ratio criterion provides a useful means of treatment evaluation as it permits dealing in maximum rather than minimum efficiency criteria.

3.1 LIVEWEIGHT/FEED CONVERSION FUNCTION

Since for each pen of birds the weight and feed consumption observations are related over time, the problem of autocorrelation will exist. While cumulative weight and feed consumption observations between pens of birds are independent, successive observations on the same pens are not. If the production function is estimated by least squares when the residuals are really autocorrelated, the estimates remain unbiased and consistent but are no longer efficient[1]. Despite this, the regressions presented in this paper, are obtained by the usual least squares procedure. The Durbin-Watson test, where applicable, for autocorrelated disturbances is found to be inconclusive; i.e. the hypothesis of positive autocorrelation can be neither accepted nor rejected.

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[1] For procedures for avoiding these problems and for the appropriate tests of significance, see D. Cochrane and G. H. Orcutt, "Application of Least Squares Regression to Relationships Containing Auto-correlated Error Terms", *Journal of American Statistical Association,* Vol. 44, No. 245 (March, 1949), pp. 32–61.

A function is fitted to liveweight, feeder-space, stocking rate data, and includes a time-in-growth variable. The form selected and coefficient values are shown below:

$$\begin{array}{llllll}
(1) & Y/F = & 0{\cdot}42194 & -\ 0{\cdot}03010 & +\ 0{\cdot}15176S & +\ 0{\cdot}00063K \\
 & & (0{\cdot}016) & (0{\cdot}003) & (0{\cdot}042) & (0{\cdot}011) \\
 & & & +\ 0{\cdot}00121T^2 & -\ 0{\cdot}09850S^2 & -\ 0{\cdot}00274K^2 \\
 & & & (0{\cdot}004) & (0{\cdot}026) & (0{\cdot}004) \\
 & & & +\ 0{\cdot}01534SK & & \\
 & & & (0{\cdot}014) & & \\
 & R^2 = & & 0{\cdot}805. & &
\end{array}$$

where Y = cumulative mean liveweight per bird, pounds;

F = cumulative feed mean consumption per bird, pounds;

T = time in weeks from trial commencement ($T = 0, 1, \ldots, 6$);

S = floor space in square feet per bird, adjusted for space occupied by feeders and also for within-trial mortality;

K = feeder space per bird; inches of feeder circumference, adjusted for within-trial mortality.

Standard errors of the coefficients are shown in brackets. The fitted equation utilizes 224 observations, 16 treatments x 2 replications x 7 weekly observations. In obtaining (1) and other similar relationships discussed below, adjustments are made in weekly S and K values to allow for bird mortality when it occurs in the respective week.

Specifying $T = 4, 6$, conversion functions are obtained for liveweights of 9 and 11 week old broilers in (2) and (3) respectively.

$$(2)\quad \text{(9 weeks)}\quad Y/F = 0{\cdot}32090 + 0{\cdot}15176S + 0{\cdot}00063K - 0{\cdot}09850S^2 - 0{\cdot}00274K^2 + 0{\cdot}01534SK.$$

$$(3)\quad \text{(11 weeks)}\quad Y/F = 0{\cdot}28490 + 0{\cdot}15176S + 0{\cdot}00063K - 0{\cdot}09850S^2 - 0{\cdot}00274K^2 + 0{\cdot}01534SK.$$

Taking partial derivatives of (2) and (3) with respect to S and K and setting to zero, input levels of floor and feeder-space are obtained which maximize conversion ratios for broilers carried to 9 and 11 weeks of age respectively[2]. Maximum point on the conversion ratio surface is

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[2] $$\frac{\partial(Y/F)}{\partial S} = 0{\cdot}15176 - 0{\cdot}19700S + 0{\cdot}01534K = 0$$

$$\frac{\partial(Y/F)}{\partial K} = 0{\cdot}00063 - 0{\cdot}00548K + 0{\cdot}01534S = 0$$

obtained using a combination of 0·996 square feet of floor-space and 2·905 inches of feeder-space. This is equivalent to approximately one square foot per bird and 16 birds per 47-inch feeder.

By substituting the S and K values so obtained into (2) and (3) the maximum conversion ratios Y/F attained at 9 weeks is 0·397 pounds, and at 11 weeks, 0·361 pounds. These are equivalent, in terms of the conventional criteria of "feed per pound of broiler", to ratios of 2·516 and 2·767 for the 9 and 11 week old birds respectively.

3.2 SINGLE INPUT FUNCTIONS

Single input curves for meat/feed efficiency are obtained for the 11 weeks old broilers by specifying the values of K which were used in the trial, and substituting S values in equation (3). Also, single input curves for Y/F with S specified at 4 levels and K varied are similarly obtained. With the number of inches equivalent to 1, 2, 3 and 4 feeders specified and substituted in equation (3), the resulting equation is a single input function of Y/F in terms of S. For one feeder, $K = 0·47$ and the single input function reduces to

$$Y/F = 0·28459 + 0·15897S - 0·09850S^2 \tag{4}$$

which, when differentiated and set to zero gives a floor-space requirement S of approximately 0·81 square feet per bird for maximum meat/feed conversion efficiency. Substituting this and other maximum-(feed) efficiency S values into the respective single input functions, corresponding maximum Y/F values are obtained. For specified K values used in the trial the required floor-space for achieving maximum Y/F efficiency and the levels of this efficiency are summarized below:

Feeder-space per bird, K	Y/F	Pounds of feed per pound of meat	Floor-space per bird, S
0·47	0·3487	2·868	0·81
0·94	0·3532	2·831	0·84
1·41	0·3567	2·803	0·88
1·88	0·3592	2·784	0·92

Single input curves for floor- and feeder-space levels used in the trial are graphed in figure 2 (a) and (b). It can be seen that the maximum Y/F, meat/feed conversion efficiency points increase for higher levels of feeder space, and that this requires successively higher inputs of floor-space.

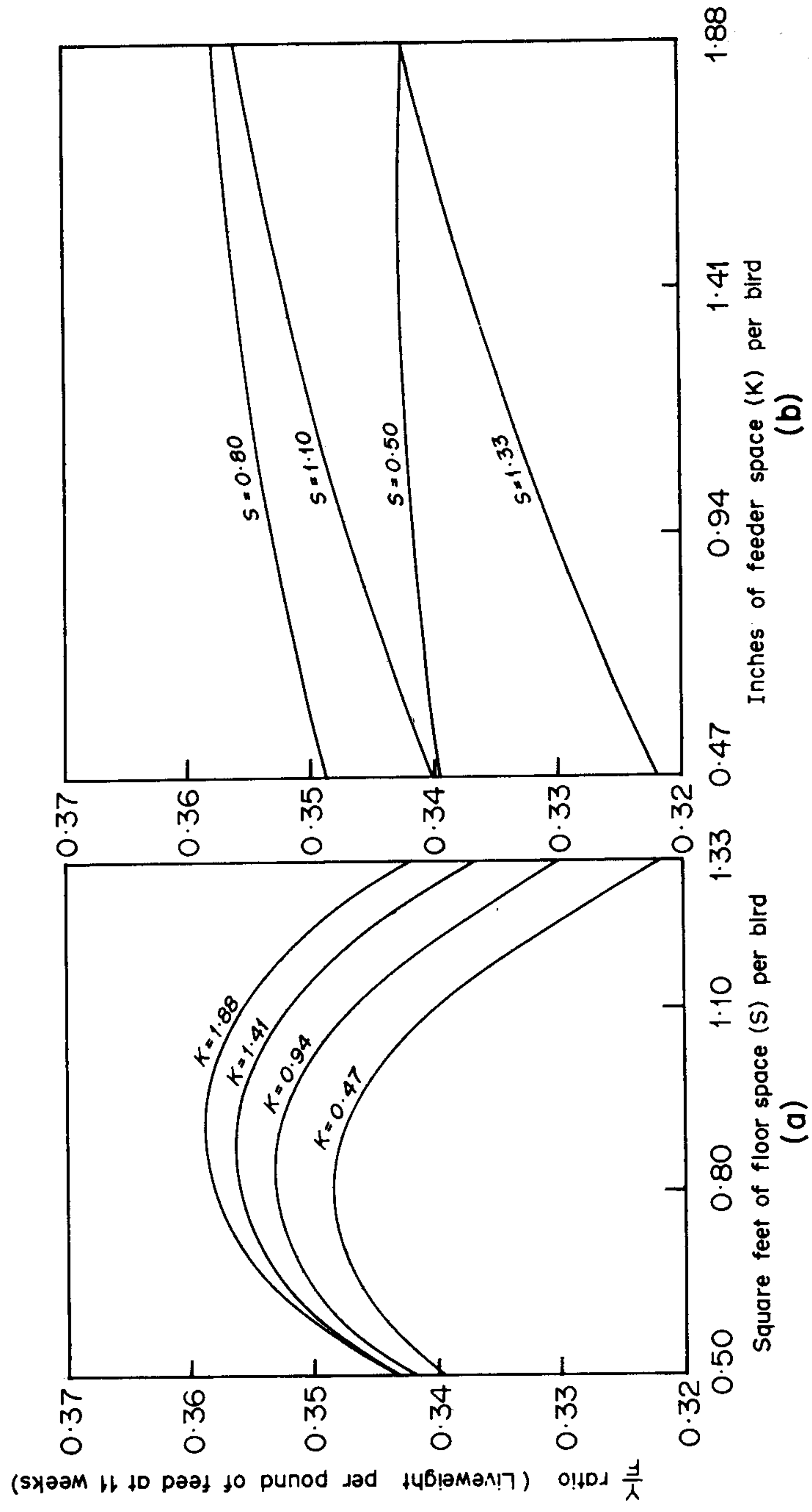

FIGURE 2

Response in Terms of Liveweight Produced per Pound of Feed, for Various Combinations of Floor-space and Feeder-space

4 LIVEWEIGHT RESPONSE TO FLOOR AND FEEDER SPACE

In this section only the liveweight response to floor- and feeder-space is considered in order to examine the economic effects of variable costs for these factors.

Functions are fitted to the total cumulative weights of birds with weekly observations being progressively totalled. Liveweight alone is admittedly an inadequate measure of production under commercial conditions. Carcass quality (appearance, tenderness, taste) adds an important output dimension which at this stage cannot be quantified[3]. There was some evidence of bruising of birds among the higher stocking rate treatments; however the trial batch cycle of 11 weeks would be 1 or 2 weeks longer than the normal broiler batch time, and this alone could be a contributing factor in deterioration in carcass quality.

The liveweight function derived is:

$$\begin{aligned} (5) \qquad Y = \; & \underset{(0{\cdot}080)}{0{\cdot}52547} + \underset{(0{\cdot}017)}{0{\cdot}10930F} + \underset{(0{\cdot}026)}{0{\cdot}30002T} \\ & + \underset{(0{\cdot}191)}{0{\cdot}61043S} + \underset{(0{\cdot}050)}{0{\cdot}14254K} - \underset{(0{\cdot}120)}{0{\cdot}31716S^2} \\ & - \underset{(0{\cdot}017)}{0{\cdot}03978K^2} + \underset{(0{\cdot}066)}{0{\cdot}03655SK} \end{aligned}$$

where Y, F, T, S and K are as defined in the previous section, and standard errors of the coefficients are provided in brackets.

Again, S and K observations are adjusted for in-trial mortality; i.e. for the number of live-birds actually in each pen at the end of each observation week. All coefficients with the exception of K^2 and SK terms are significant at 1 per cent level. The coefficient for K^2 is significant at 5 per cent level. The coefficient of multiple determination of 0·988 is also significant at 1 per cent level. Equation (5) is used as the best liveweight predicting model. Terms such as F^2, T^2, and FT when included accounted for only insignificant variation and hence were dropped. Also a square root-type production function was tried, but found unsatisfactory in several respects and hence is not presented here.

For the purpose of economic analysis of factors of interest, S and K, the terms F and T have to be specified at some level. As the average total feed consumption per bird over the trial period was recorded at 11·53125 pounds, feed input F is fixed at this level in the following analysis. Also, since the chickens attained an age of 11 weeks (from day-old) the variable T is fixed at 6 corresponding to an actual age of 11 weeks. For these values of F and T the production function is given by (6).

$$\begin{aligned} (6) \qquad Y = \; & 3{\cdot}58596 + 0{\cdot}61043S + 0{\cdot}14254K - 0{\cdot}31716S^2 \\ & - 0{\cdot}03978K^2 + 0{\cdot}03655SK. \end{aligned}$$

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[3] In other work at Laureldale, trial B1–67, carcass quality and consumer acceptance of broilers fed rations based on 20 grain combinations are specifically evaluated as outputs of the trial, in addition to the conventional response in terms of liveweight gain.

4.1 PRODUCTION SURFACE AND PREDICTED MAXIMUM LIVEWEIGHTS

Relevant detail concerning the response curves is provided to indicate the nature of the underlying production surface. Table 1 shows the predicted liveweights per bird for different combinations of S and K which were used in the trial, based on equation 6. Decreasing total returns are evident for floor space but not for feeder space.

TABLE 1

Predicted Pounds Liveweight per Bird Attained by Trial Broilers with Combinations of Shed Space S and Feeder Space K

Feeder space per bird, K	Square feet of floor space per bird, S			
	0·50	0·80	1·10	1·33
inches	lb	lb	lb	lb
0·47	3·89	3·94	3·95	3·92
0·94	3·93	4·00	4·01	3·98
1·41	3·96	4·03	4·05	4·03
1·88	3·97	4·05	4·08	4·06

Figure 3 illustrates geometrically the production surface predicted by equation (6). The output for $S = 0$ and $K = 0$ is not meaningful, being included only for completeness of the model. The surface illustrates high marginal products for up to 0·80 units of S. After this point the predicted chicken liveweight response to shed space S flattens out and diminishes slightly at the highest input level reached in the trial. The

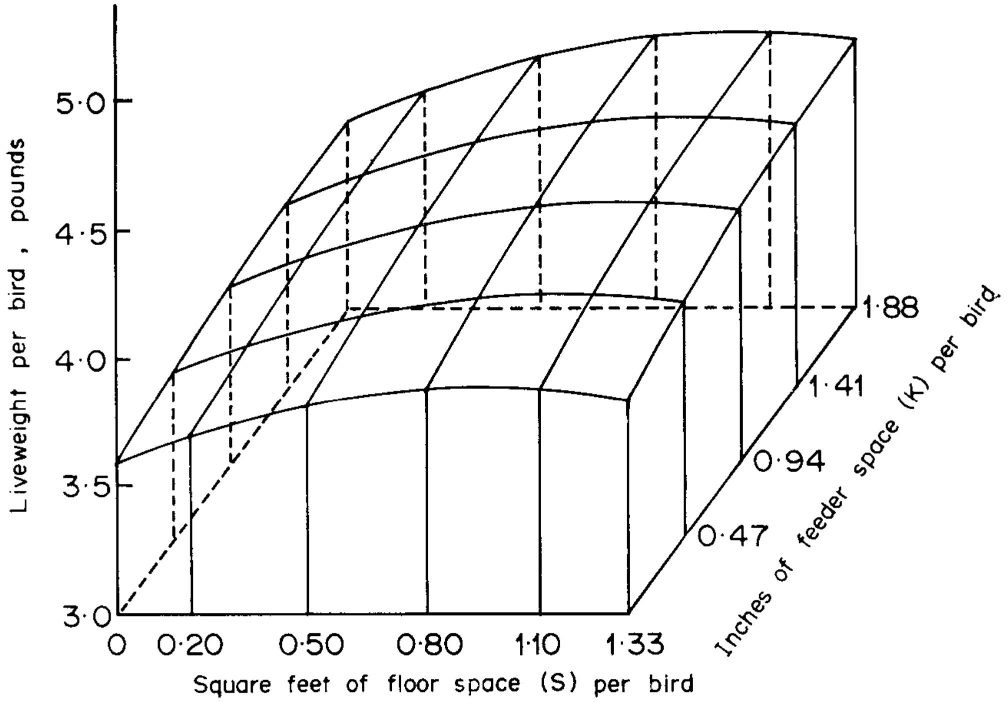

FIGURE 3

Broiler Liveweight Response to S and K highest marginal response to feeder space occurs for $K = 0{\cdot}94$, after which level of feeder space the output response increases at a decreasing rate.

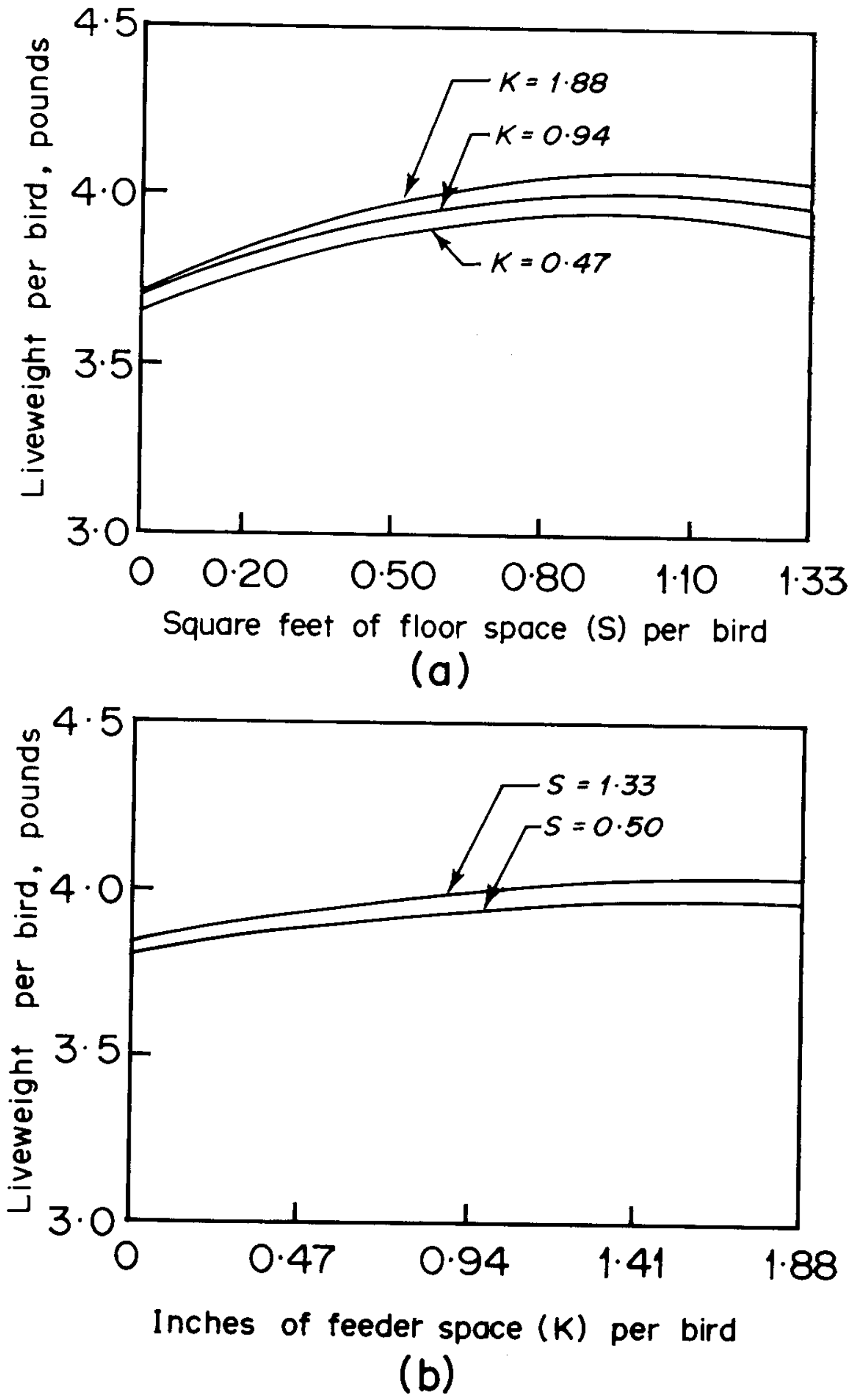

FIGURE 4

Liveweight Response: (a) to Shed Space S, with K Constant at three Levels; (b) to Feeder Space K, with S Constant at two Levels

For the production surface shown in figure 3, single-input curves are obtained for inputs S and K by holding K and S constant. These are shown in figure 4.

4.2 MARGINAL PHYSICAL PRODUCTS

Marginal physical products of shed- and feeder-space are predicted from the partial derivative equations (7) and (8).

$$\text{(7)} \qquad \frac{\partial Y}{\partial S} = 0{\cdot}61043 - 0{\cdot}63432S + 0{\cdot}03655K$$

$$\text{(8)} \qquad \frac{\partial Y}{\partial K} = 0{\cdot}14254 + 0{\cdot}03655S - 0{\cdot}07956K$$

Table 2 provides marginal physical product data, obtained by substituting input values into (7) and (8). When feeder space is held constant at 0·47 the marginal physical product of floor space S becomes negative when its level is above 0·99 square feet per bird. As figure 4 shows, the marginal physical products of either S or K at any given level increase as the specified level of the other factor is increased.

TABLE 2
Marginal Physical Products for Floor Space S and Feeder Space K

Feeder space per bird	S square feet per bird			
	0·50	0·80	1·10	1·33
inches	lb	lb	lb	lb
0·47	0·3104	0·1202	—0·0701	—0·2160
0·94	0·3276	0·1373	—0·0530	—0·1988
1·41	0·3448	0·1545	—0·0358	—0·1817
1·88	0·3620	0·1717	—0·0186	—0·1645

Floor space per bird	K inches of feeder space per bird			
	0·47	0·94	1·41	1·88
square feet	lb	lb	lb	lb
0·50	0·1234	0·0860	0·0486	0·0112
0·80	0·1344	0·0970	0·0596	0·0222
0·10	0·1454	0·1080	0·0706	0·0332
1·33	0·1538	0·1164	0·0790	0·0416

With first partial derivatives of (6) with respect to S and K set to zero, the maximum liveweight production and corresponding input quantities are derived: predicted maximum liveweight is 4·08 pounds per chicken obtained with 1·09 square feet of space per bird and with 2·29 inches of feeder space (or about 20 birds per 47 inch feeder).

4.3 ISOQUANTS

The isoquant equation expressing the amount of floor space necessary for producing a specified liveweight level as a function of feeder space is given in (9)

$$(9)\quad S = 1{\cdot}92469 + 0{\cdot}11525K + (48{\cdot}93038 - 12{\cdot}61193Y + 2{\cdot}24141K - 0{\cdot}48842K^2)^{\frac{1}{2}}$$

where Y denotes the specified production level in pounds per bird. Isoquants for selected liveweight levels of 3·90, 3·96 and 4·02 pounds are derived from (8) and shown in figure 5. Being convex to the origin they indicate the range for possible rational substitution of feeders for shed space. Isoquant schedules and marginal rates of substitution for the above liveweight levels are given in table 3.

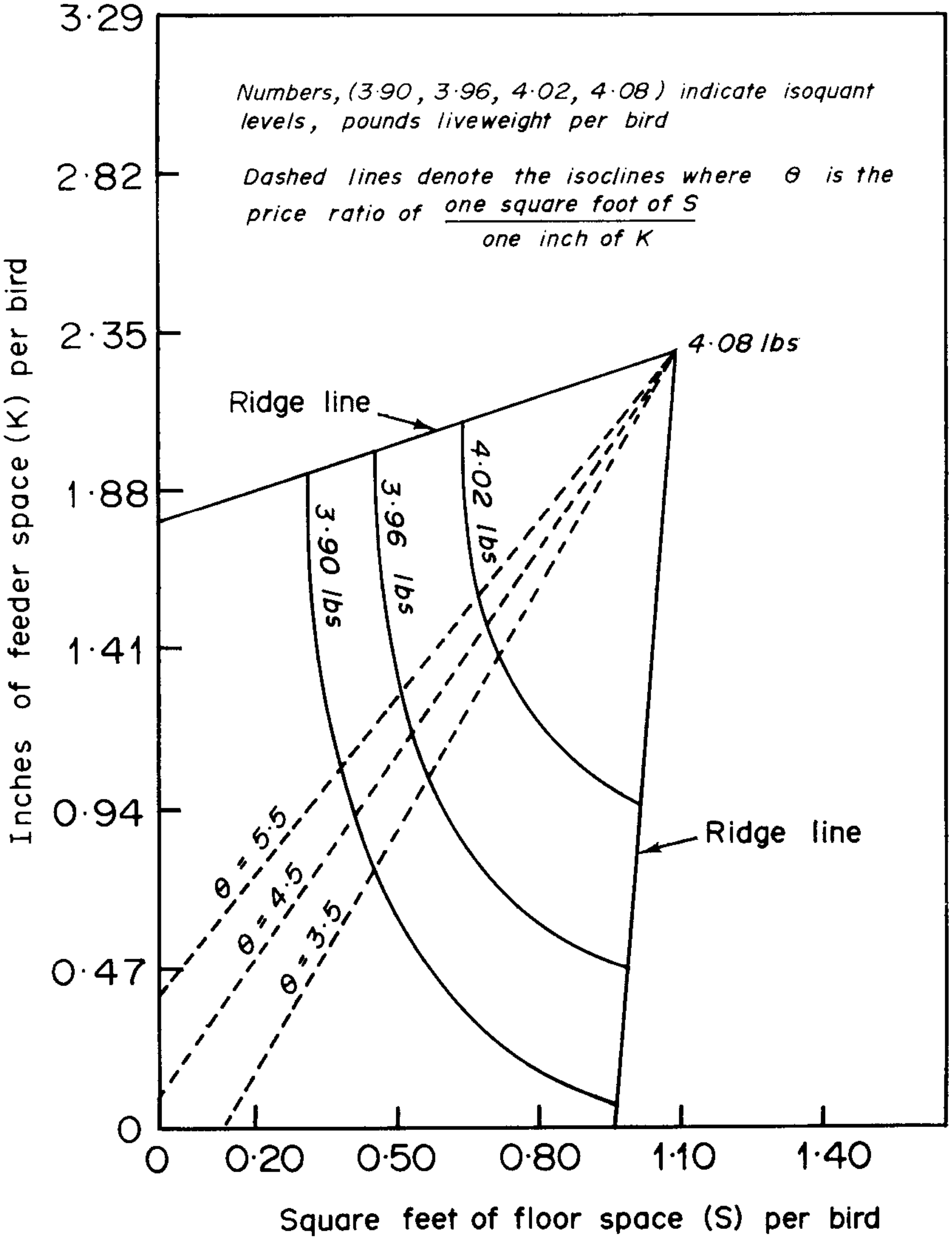

FIGURE 5

Yield Isoquants and the Isoclines for S and K, based on Equations (6) and (9)

TABLE 3

Combinations of Shed Space and Feeder Space Required to Produce Specified Liveweight Levels at Eleven weeks, and Marginal Rates of Substitution
(F = 11·5313 and T = 6)

Production level, pounds liveweight per bird								
3·90			3·96			4·02		
K	*S*	*MRS*	*K*	*S*	*MRS*	*K*	*S*	*MRS*
0·235	0·729	0·9614	0·705	0·718	0·6237	1·175	0·812	0·5700
0·470	0·574	0·4790	0·940	0·610	0·3487	1·410	0·720	0·2758
0·705	0·483	0·3157	1·175	0·544	0·2234	1·645	0·671	0·1479
0·940	0·421	0·2200	1·410	0·501	0·1415	1·880	0·647	0·0618
1·175	0·378	0·1519	1·645	0·475	0·0788	. .	. .	. .
1·410	0·348	0·0977	1·880	0·463	0·0257	. .	. .	. .

4.4 MARGINAL RATES OF SUBSTITUTION AND THE ISOCLINES

Marginal rates of substitution are predicted by (10).

$$(10)\qquad \frac{\frac{\partial Y}{\partial K}}{\frac{\partial Y}{\partial S}} = \frac{\partial S = 0{\cdot}03655S - 0{\cdot}07956K + 0{\cdot}14254.}{\partial K = 0{\cdot}03655K - 0{\cdot}63432S + 0{\cdot}61043}$$

Substitution rates from (10) are suggestive of input factor ratios that will allow attainment of a specified liveweight level with minimum factor costs.

For specified per bird liveweight levels as in table 3, cost-minimizing inputs of shed and feeder space can be obtained in the usual way by equating marginal substitution rates and the inverse factor price ratio, here

$$(11)\qquad \frac{Pk}{Ps} = \frac{\partial S}{\partial K} = \frac{0{\cdot}03665S - 0{\cdot}07956K + 0{\cdot}14254.}{0{\cdot}03655K - 0{\cdot}63432S + 0{\cdot}61043}$$

Determination of per unit feeder space price, *Pk*, and shed space price *Ps* for this purpose is discussed in Section 5.1 below.

The isocline family is described in equation (12).

$$(12)\qquad 0 = (0{\cdot}63432 + 0{\cdot}03655\theta)S - (0{\cdot}03655 + 0{\cdot}07956\theta)K - (0{\cdot}61043 - 0{\cdot}14254\theta)$$

where θ is the constant (specified) price ratio *Pk*/*Ps*.

For specified values of θ, equation (12) describes the least-cost combination of floor and feeder space and thus identifies the production expansion path. Isoclines for three different values of θ are presented in figure 5. They are straight lines and converge at the factor combination giving the maximum live-weight attainable. Here a liveweight of 4·08 pounds is obtained with a floor-space input of 1·09 sq ft and 2·29 inches of feeder space.

5 ECONOMIC IMPLICATIONS

In this section the economic implications of the foregoing physical analysis are briefly summarized.

5.1 COSTS AND PRICES

INPUT COSTS

Prices of shed space and feeders must be specified in terms of fixed costs per bird per batch. Cost of these items is subject to some variation between broiler-growing regions but this equipment is rapidly becoming standardized. Based on a survey of growers' investment in the Tamworth, Newcastle and Sydney areas, annual cost per square foot of shed space is set at 7·20 cents[4]. Annual average cost of feeders is set at 75 cents or approximately 1·6 cents per inch[5]. The shed space cost includes necessary ancillary items such as hessian blinds, feed trolley, brooders.

Because of the dynamic nature of the broiler industry, obsolescence is a larger factor in depreciation than is physical wear-and-tear on plant. Doubtless, depreciation does vary to some extent with the level of intensity at which the broiler operation is run; but this has not been quantified. For this reason annual per unit shed and feeder costs are treated as fixed rather than variable costs. Thus it is assumed the above costs would apply at each level of intensity represented by production of from 1 to 4 batches annually, and shed and feeder space cost per batch would be reduced proportionately if 2, 3, 4, batches rather than one batch annually is grown.

PRODUCT PRICE

Liveweight on-farm broiler prices are tending downwards. Recent processor-grower contract prices have ranged around 20 cents per pound, with 20 cents prevailing in the Tamworth area over most of 1967. Three price levels are considered here: 18, 20, and 22 cents per pound.

5.2 OPTIMAL FLOOR- AND FEEDER-SPACE FOR A RANGE FOR PRICE SITUATIONS

Using price and cost levels discussed in 5.1 the optimal level of space inputs is determined in (13) and (14) by equating first partial derivatives of the production function, and shed space/product price ratio, Ps/Py and feeder space/product price ratio, Pk/Py.

$$(13)\qquad -0{\cdot}63432S + 0{\cdot}03655K + 0{\cdot}61043 = \frac{Ps.}{Py}$$

$$(14)\qquad 0{\cdot}03655S - 0{\cdot}07956K + 0{\cdot}14254 = \frac{Pk.}{Py}$$

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[4] Initial shed cost of $613.60 per 1,000 sq ft, depreciated over 15 years. Annual fixed cost consists of depreciation of $40.91, interest on average investment at 6 per cent, annual maintenance at 2 per cent of new cost, $12.27. Investment cost data from David M. Gibson, *Some Comparisons of Broiler Grower Returns in Three Producing Centres*, (University of New England, Farm Management Report No. 13, forthcoming).

[5] New cost of $3.30 depreciated over 5 years; interest added, but no maintenance assumed.

TABLE 4

Profit Maximizing Combinations of Shed and Feeder-Space for Various Input and Product Prices

Situation Number	Price per unit			Optimum inputs		Predicted live-weights
	Live-weight per pound	Floor space	Feeder space per inch	*S* floor space	*K* feeder space	
	cents	cents	cents	sqft/ bird	in/bird	lb/bird
1	22·0	7·20	1·60	0·5105	1·1121	3·9450
2	22·0	7·20	0·80	0·5375	1·5816	3·9795
3	22·0	7·20	0·53	0·5467	1·7400	3·9872
4	22·0	7·20	0·40	0·5511	1·8163	3·9903
5	22·0	3·60	1·60	0·7755	1·2338	4·0189
6	22·0	3·60	0·80	0·8025	1·7033	4·0489
7	22·0	3·60	0·53	0·8117	1·8618	4·0552
8	22·0	3·60	0·40	0·8160	1·9381	4·0575
9	22·0	2·40	1·60	0·8638	1·2744	4·0339
10	22·0	2·40	0·80	0·8908	1·7439	4·0624
11	22·0	2·40	0·53	0·9000	1·9024	4·0682
12	22·0	2·40	0·40	0·9044	1·9786	4·0703
13	22·0	1·80	1·60	0·9080	1·2947	4·0396
14	22·0	1·80	0·80	0·9350	1·7642	4·0674
15	22·0	1·80	0·53	0·9442	1·9226	4·0729
16	22·0	1·80	0·40	0·9486	1·9989	4·0749
17	20·0	7·20	1·60	0·4521	0·9938	3·9159
18	20·0	7·20	0·80	0·4818	1·5103	3·9576
19	20·0	7·20	0·53	0·4919	1·6846	3·9670
20	20·0	7·20	0·40	0·4967	1·7685	3·9707
21	20·0	3·60	1·60	0·7436	1·1278	4·0053
22	20·0	3·60	0·80	0·7733	1·6442	4·0416
23	20·0	3·60	0·53	0·7834	1·8185	4·0492
24	20·0	3·60	0·40	0·7882	1·9024	4·0521
25	20·0	2·40	1·60	0·8407	1·1724	4·0234
26	20·0	2·40	0·80	0·8705	1·6889	4·0580
27	20·0	2·40	0·53	0·8805	1·8631	4·0650
28	20·0	2·40	0·40	0·8854	1·9470	4·0675
29	20·0	1·80	1·60	0·8893	1·1947	4·0303
30	20·0	1·80	0·80	0·9191	1·7112	4·0640
31	20·0	1·80	0·53	0·9291	1·8854	4·0707
32	20·0	1·80	0·40	0·9339	1·9694	4·0731
33	18·0	3·60	1·60	0·7046	0·9981	3·9870
34	18·0	3·60	0·80	0·7376	1·5719	4·0318
35	18·0	3·60	0·53	0·7488	1·7656	4·0412
36	18·0	3·60	0·40	0·7542	1·8588	4·0447
37	18·0	2·40	1·60	0·8125	1·0477	4·0094
38	18·0	2·40	0·80	0·8456	1·6215	4·0520
39	18·0	2·40	0·53	0·8567	1·8152	4·0607
40	18·0	2·40	0·40	0·8621	1·9084	4·0638
41	18·0	1·80	1·60	0·8665	1·0725	4·0178
42	18·0	1·80	0·80	0·8996	1·6463	4·0594
43	18·0	1·80	0·53	0·9177	1·8400	4·0677
44	18·0	1·80	0·40	0·9161	1·9332	4·0706

In table 4, 3 levels of liveweight price, and 4 levels of shed space and feeder space prices as defined in section 5.1 are specified, and corresponding maximum-profit space combinations are derived by application of (13) and (14).

Table 4 illustrates the necessary change in profit-maximizing space combinations with relative liveweight price and factor cost changes. For example, for any grower with input prices as specified in section 5.1 and receiving 20 cents per pound, the two-batch optimum combinations (situation 22 in table 4) is 0·77 square feet per bird and 1·64 inches of feeder space. Predicted liveweight at 11 weeks is 4·0416 pounds.

Costs under situation 22 would be appropriate if the input prices specified in section 5.1 were effective, and if two batches annually were produced. For 3 and 4 batches annually the relevant situations are 27 and 32.

When all major and direct costs are considered—day-old chickens and feed as well as shed and feeder space—total profit margins per bird for each trial treatment are expressed by equation (15).

(15) Total profit margins $= YPy - Pc - FPf - KPk - SPs$

where Y is defined by the production function given in equation (6);
Py, Pk, Ps are as defined in previous sections;
Pc = the cost per day-old chick;
F = the feed consumed in time T;
Pf = feed price per pound.

Setting $T = 6$ (i.e., 11 weeks in total), Py at the most likely liveweight price of 20 cents, chicken and feed costs at 16 and 4·175 cents respectively, F at 11·5312 pounds, and taking per unit shed and feeder space costs appropriate to 1, 2, 3 and 4 batches per years, margins per bird for the 16 combinations of S and K used in the trial are obtained. These are shown in table 5.

TABLE 5

Total Profit Margins Per Bird Under Sixteen Combinations of Shed and Feeder Space Used in Trial

Number of feeders	Number of batches	Birds per 80 square feet			
		160	100	73	60
		cents	cents	cents	cents
1	1	8·41	7·76	6·07	3·99
1	2	10·40	10·98	10·47	9·33
1	3	11·07	12·05	11·94	11·11
1	4	11·40	12·59	12·67	12·00
2	1	8·69	8·13	6·55	4·45
2	2	10·89	11·69	11·40	10·36
2	3	11·62	12·88	13·02	12·34
2	4	11·99	13·47	13·82	13·32
3	1	8·81	8·18	6·61	3·93
3	2	11·24	12·05	11·09	10·39
3	3	12·06	13·34	12·59	12·54
3	4	12·46	13·98	13·34	13·61
4	1	8·80	7·84	5·38	2·41
4	2	11·44	12·04	11·15	9·41
4	3	12·32	13·45	13·08	11·76
4	4	12·76	14·14	14·04	12·91

APPENDIX

Summary of Trial Treatments, and Liveweight and Cumulative Feed Consumption Per Bird at Eleven Weeks for 32 *Treatments, Pen Means*

Pen Nos	Birds* per pen	Feeders per pen	Birds* per feeder	Liveweight	Feed Consumption
	number	number	number	pounds	pounds
5.	60	1	60	4·20	12·07
32.	60	1	60	3·93	11·73
11.	60	2	30	4·39	12·69
18.	60	2	30	4·08	12·83
14.	60	3	20	4·15	12·41
23.	60	3	20	4·01	11·48
4.	60	4	15	4·10	10·68
25.	60	4	15	4·13	11·80
15.	73	1	73	3·98	11·52
26.	73	1	73	3·78	11·71
3.	73	2	37	4·03	11·94
22.	73	2	37	4·23	11·82
8.	73	3	24	4·01	11·55
17.	73	3	24	4·25	11·98
12.	73	4	18	4·10	11·73
29.	73	4	18	3·83	11·23
9.	100	1	100	4·07	11·62
20.	100	1	100	4·15	11·12
7.	100	2	60	3·92	11·44
30.	100	2	60	3·99	11·19
27.	100	3	33	3·97	11·05
2.	100	3	33	4·08	11·96
16.	100	4	25	3·80	11·65
21.	100	4	25	4·18	11·42
1.	160	1	160	3·66	10·87
24.	160	1	160	3·34	10·28
13.	160	2	80	3·87	10·86
28.	160	2	80	3·76	11·16
10.	160	3	53	3·87	11·41
31.	160	3	53	3·88	11·49
6.	160	4	45	3·87	11·34
19.	160	4	45	3·78	10·97

* Nominal values shown are to be adjusted slightly to account for in-trial mortality which occurred randomly through the various treatments.