DIETARY FIBRE DILUTION AS A MEANS FOR CONTROLLING BROILER BREEDER GROWTH

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by

Robert Ian McKay

Department of Animal Science

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ABSTRACT

Preliminary studies with SCWL cockerels were conducted to determine the effect of fibre diluted diets on growth and nutrient intake. With the inclusion of 10% added fibre, a significant compensatory increase in food consumption limited the depression in growth. At 15% added fibre, however, the adaptive response was minimal as evidenced by the 15% reduction in weight in chicks fed pelleted diets and 20% reduction in those fed non-pelleted diets. This information was applied to the formulation of broiler breeder starter and grower diets so that these would, theoretically, be as effective as the recommended commercial feeding systems for controlling growth. The skip-a-day system was used as a control and included two diets, one wheat-soy based and the other containing 40% rye grain as replacement for wheat. The restricted rye fed birds weighed 22% less than the full fed birds at 20 weeks of age, whereas only a 19% reduction was observed with the restricted wheat and 18% with the full fed fibre group.

Subsequent breeder preformance was evaluated based upon the influence of the grower regimes. Hen-day egg production for the four months following 50% production was as follows: restricted rye, 71.4%; restricted wheat, 67.1%; full fed wheat, 62.0%; and full fed fibre, 60.8%. Egg weight was significantly smaller with the fibre fed group (57.5 gm) when compared to the restricted wheat (59.1 gm) or full fed wheat (59.3 gm) group. No significant differences in fertility or hatchability were observed. Our studies indicate that fibre dilution as a means of early feed restriction for broiler breeder pullets is not practical. Rye, fed

at 40% of grower and layer rations, was effective and this treatment deserves further investigation.

Concurrently with the performance data collected in all trials, the influence of the grower regimes on nutrient balance, gastrointestinal development and rate of passage was determined. Significant influences of high fibre and rye feeding were evident; although no differences with restricted versus full feeding were notable. High fibre feeding resulted in lower calcium retention (i.e. 18.4% for a high fibre group versus 51.2% for the control group) and lower fat retention (84.1% for a high fibre diet versus 88.9% for the control regime), liver weight which was 50% smaller than the full fed wheat group at 20 weeks and a consistently heavier ventriculus, ileum and colon than those found for the other treatment groups. Fibre feeding also resulted in faster rates of passage during the day when feed was available. The relationship of these effects to performance is discussed. The negative influences of rye feeding (i.e. a tendency toward lower nitrogen and fat retention) and the slower rates of passage had a minimal influence with these birds which were fed on a skip-a-day basis.

Comparison of three methods of statistical analysis of organ measurements indicated that when significant body weight effects are apparent, a regression model should be employed. Development of intestinal length is rapid and seems to be relatively independent of nutritional stimuli, whereas weight development is more gradual and can be influenced by environmental factors.

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ABBREVIATIONS

cm - centimetre

gall blad. - gall bladder

gm - grams

kcal - kilocalories

kg - kilograms

ME - metabolizable energy

MEn - nitrogen corrected metabolizable energy

mg - milligrams

NPPF - non-purified plant fibre

PF - plant fibre

PPF - purified plant fibre

provent. - proventriculus

SCWL - single combed white leghorn

S.E. - standard error

ventric. - ventriculus

vit. - vitamin

wt. - weight

INTRODUCTION

Less than 60% of all broiler chicks raised in Manitoba are derived from indigenous broiler breeder flocks (personal communication, D. Waddell, 1980). The severe management and labour demands during the growing and laying phase described in typical broiler breeder supplier manuals (i.e. Hubbard Farms, 1978) discourage further development in this area. Existing flock managers are reported to be having problems coping with the complex feeding systems necessary to maintain recommended body weights and this has been reflected in the relatively poor productivity of these birds.

Several alternative methods to the recommended quantitative, skip-a-day system of feeding have been attempted and, generally, have met with limited success. Controlling growth using fibre diluted diets has been reported to be successful in some experiments (Summers et al., 1967; Kondra et al., 1974), while being completely rejected in another (Waldroup et al., 1976). Literature in this field becomes rapidly outdated because of the genetic advances in broiler growth rate. Few studies using early introduction (i.e. at 3 weeks of age) of alternative restriction regimes have been reported.

Essentially no research has been conducted to determine the nutritional, physiological and anatomical relationship of the restriction methods with subsequent performance. Information concerning these effects might permit a more direct tailoring of nutritional programmes to minimize labour and feed costs, while optimizing production.

The objective of the present study was to evaluate the effectiveness of a high fibre broiler breeder diet, introduced early in the grower

phase, for controlling development and improving layer performance. Rye replacement of wheat was included as an additional grower and layer diet to complement a much larger co-operative study assessing the feeding value of rye grain for animal production. Nutritional, anatomical and physiological studies were included in an attempt to explain the effects of the dietary regimes on performance.

LITERATURE REVIEW

I. FIBRE IN POULTRY DIETS

A. General

Fibre is a poorly defined, but significant component of the diet of most species and has been largely ignored in most studies until recently. Interest developed initially when a lower incidence of gastro-intestinal disease in humans was related to an observed higher dietary fibre intake. Since then, a number of books (Spiller and Amen, 1978; Spiller, 1978; Inglett and Falkehag, 1979), a journal supplement (Roth, 1978) and several reviews (Spiller and Amen, 1972; Van Soest and Robertson, 1977; Theander, 1977; Eastwood, 1977; Southgate, 1977; Spiller et al., 1978; Van Itallie, 1978) have been published concerning the precise identification, physical and chemical characterization, and physiological effects of dietary fibre.

Southgate (1977) describes a general classification scheme for fibre consisting of cellulose components, non-cellulosic polysaccharides and lignin. Cellulose is a β-linked polyglucan, noted for its poor solubility in water, and usually comprising a major portion of the analytical "crude fibre" and "acid detergent fibre" found in animal feeds. Apart from cellulose, lignin is the most abundant dietary fibre. It is not composed of carbohydrate subunits, but consists of a complex arrangement of substituted phenylpropanes (Spiller and Amen, 1978). Lignin has proven difficult to isolate and purify for detailed nutritional studies (Leitzmann et al., 1979). Non-cellulosic polysaccharides consist of two fractions: one more readily soluble in water and the other soluble

when ester linkages to lignin are cleaved in alkali (Van Soest and Robertson, 1977). This latter group is also referred to as the hemicellulose fraction.

Further classification, important for research purposes, has been recommended by Spiller and Amen (1972) to separate plant fibre (PF), a general term for plant cell wall constituents, into two groups: non-purified plant fibre (NPPF) which refers to the plant cell wall in its natural state, and purified plant fibre (PPF) to distinguish such structural polymers as cellulose or pectin that have been isolated and purified.

B. Effect on growth and nutrient utilization

The unique nature of the avian digestive system, with its poorly developed large intestine and rapid rates of food passage, prevents any significant microbial degradation of cellulose or most other fibre components (Scott et al., 1976). Thus, the chicken is not a suitable biological model for studying lower gut metabolism, where dietary fibre in monogastrics is thought to have its primary effect. The literature involving poultry in detailed fibre research is minimal.

The major influence of added fibre in poultry diets has been to act as a diluent. Hill and Dansky (1954) fed varying levels (up to 40%) of oat hulls to chicks and measured growth and feed intake. The highest level of added NPPF resulted in an 8% reduction in body weight gain with a 34% increase in total feed intake. The lower productive energy intake could be directly related to decreased carcass fat content. A similar study by Scott et al. (1958) with ducks, using wheat bran as a diluent, indicated that 80% of the reduced weight of the high fibre group could be attributed to lower carcass fat content. In these studies, no adverse

effect on basal feed utilization was found; the primary effect was an overall reduction in caloric intake.

A few reports have described the growth-promoting effects of cellulose (Davis and Briggs, 1947) and of a specific hemicellulose (Fahey, 1979). Additional benefits of fibre inclusion in animal diets, such as detoxifying properties and protection against known carcinogens, are summarized by Kritchevsky (1977). Specific practical incidences of improved performance with poultry are rare, although subjective appraisals such as improved feathering and less irritable behaviour with high fibre diets are more common (Summers et al., 1967; Kondra et al., 1974).

Recent studies have emphasized the negative influence of fibre on basal feed conversion. Dvorak and Bray (1978) noted a significant increase in basal feed to gain ratios for broiler chicks fed a diet containing 20 and 30 percent added cellulose; but no differences were seen at the 10% level. Bayer et al. (1978) found poorer feed efficiency with as little as 6% added cellulose when birds were trained to be meal eaters, i.e. consuming food for a one-half hour interval three times daily. Other PPF's, for example pectins (Rao and Bright-See, 1979), have also been reported to cause reduced growth and impaired feed utilization. Thus, in addition to causing lowered feed intake, increased dietary fibre can interfere with nutrient retention.

Lipid and nitrogen retention

The discovery that dietary fibre can increase cholesterol or bile acid turnover and therefore might influence the incidence of heart and other circulatory disorders in humans has led to a large amount of

research in this area. The significance of these reports to the present discussion is limited. The more general effect of dietary fibre on lipid absorption and metabolism in poultry has not been thoroughly investigated.

Akiba and Matsumoto (1978) used ^{131}I-triolein to study fat absorption and metabolism in chicks force-fed purified diets containing 0, 4 and 8% cellulose. Although no significant differences in the absorption of these three diets were detected, a significant decrease in liver lipid accumulation was noted. Further, they determined that feeding cellulose markedly reduced the triglyceride content of the liver. The authors concluded that cellulose does affect lipid metabolism; the nature of these effects requires more investigation. Feeding chicks a diet containing pectin resulted in a marked reduction in fat absorption (Fisher et al., 1964). This result has been supported in experiments with humans, summarized by Story and Kritchevsky (1978), which indicate lower serum lipid levels with pectin, but not bran or cellulose supplemented diets.

Studies described by Fahey (1979) generally determined that moderate additions of purified fibres to poultry diets tend to improve nitrogen balance. Practical rations supplemented with natural fibres, also tended to increase nitrogen retention in swine. Corley et al. (1978) found that a corn-soy diet containing 4% solka-floc, but not hydrolysed alpha-cellulose, improved nitrogen retention. They hypothesized that the positive effects attributable to the less purified fibre sources might be due to the soluble hemicellulose fractions.

Mineral metabolism

Initial enthusiasm for the inclusion of fibre in human diets has been tempered recently by the discovery that interferences may occur with mineral metabolism. High fibre diets fed to humans in the form of whole meal bread resulted in a significant reduction in calcium, magnesium, zinc and phosphorus retention (Reinhold et al., 1976). Further investigation using several NPPF sources with varying levels of protein confirmed the negative correlation between fibre content and divalent (calcium and magnesium) retention, but reported that zinc and phosphorus were more dependent on protein (Sandstead et al., 1979) or dietary phytate levels (Davies et al., 1977). A number of studies described by Cummings (1978) have substantiated the negative influence of fibre on calcium retention; however the author feels that studies related to long term adaptation should be undertaken.

Several researchers have begun to look at the "in vitro" cation retaining properties of PF. Using a titratable incubation mixture, Thompson and Weber (1979) mimicked physiological pH changes along the gastrointestinal tract. They found that substantial binding of endogenous copper, zinc and iron to five NPPF (wheat bran, corn bran, rice bran, soy bran and oat hulls) and cellulose would occur in the more alkaline areas of the gut. Methods established to relate cation exchange capacities of various fruit and vegetable fibres involving acid base titration (Eastwood and Mitchell, 1978) led to the conclusion that these fibres act as "monofunctional, weak resins".

Current trends emphasize the importance of using purified plant fibres to establish more specifically the structures responsible for

effecting mineral availability. Viola et al. (1970) measured apparent calcium retention in rats fed several PPF types. A significant depression in calcium retention was found with pectins, algins and cellulose. Another study of various pectinaceous fibres (Furda, 1979) related degree of esterification to calcium binding. It was concluded that calcium ions are bound electrostatically, the strength of which is dependent upon the charge density along the molecule.

Literature concerning the influence of fibre on mineral metabolism in chickens or swine is limited. Griffith et al. (1961) have described the depression in apparent calcium retention with cellulose added at 3, 6 and 12% of a purified ration. In addition the paper describes an interrelationship with dietary fat, an increase in dietary lipid improving absorption of the element at high fibre levels. Nwokolo and Bragg (1977) correlated the endogenous crude fibre content of protein supplements for growing chicks with mineral availability. They found a consistent negative correlation with fibre level for phosphorus and zinc in particular, but also with calcium, magnesium and manganese. High cellulose diets have been reported to reduce apparent absorption of potassium, calcium, phosphorus, magnesium and zinc in swine (Partridge, 1978).

C. Rye grain - a unique fibre component

For a complete review of the field of rye research relevant to animal production refer to Antoniou (1980). The precision of the crude fibre technique for analysis of indigestible material becomes questionable in cases such as rye where the pentosan content, nearly 10%, is much greater than the crude fibre content (≈2.6%).

The presence of these pentosans has been regarded as the predominant factor in reducing growth and impairing nutrient retention. Antoniou (1980), also emphasized that there is considerable age dependent adaptation responsible for an improvement in performance with time. It was recommended, based upon unpublished data (personal communication with L. Campbell, University of Manitoba) that 40% rye could be incorporated into grower and layer rations without adversely affecting performance.

II. BREEDER PULLET REARING - GROWTH RESTRICTION

A. General

Research relating to broiler breeder pullet rearing has evolved in the early fifties from concern for feed savings (reduced cost) to, more recently, an emphasis on specifically controlling body weight to increase productivity. This latter development parallels the extremely effective programme for genetic improvement in broiler growth rates. Several elaborate and often confusing nutritional schemes have resulted to mediate these two confounding pressures: growing and maintaining parents at body weights which optimize production while producing offspring with rapid growth rates. The methods developed can be grouped into two categories: quantitative restriction which limits, directly or by time, the quantity of food given; or qualitative restriction. This latter method involves altering nutrient composition to control growth while maintaining a full feed system.

The literature published in this area has been inadequate, intermittent and often conflicting due to several factors including high research costs and specialized housing requirements, strain and environ-

ment (seasonality, range versus confinement rearing etc.) differences and the variable methods of performance evaluation. The latter point presents a particular problem. Although such parameters as delay in sexual maturity generally resulting in increased number of settable eggs (Lee et al.,1971b), day to 50% production, peak production, % hen-day production, % hen-house production or simply, body weight at the end of the grower period can provide some useful indications of the appropriateness of a particular diet or dietary regime; the evaluation is not complete until cost analysis (feed and labour time) are considered (Peters et al., 1972; Cave, 1978).

Isaacks et al. (1960) have concluded from research published prior to 1960 that: "restriction of either feed intake or reduced caloric intake, if severe enough, will delay sexual maturity and reduce body weight during the growing period; but that restriction has no effect on egg size, egg production or final body weight". Thus, the initial role of these feeding regimes was to reduce overall feeding costs. Subsequent research has emphasized the improved productive capacity as a result of restricted feeding programmes. In general restricting feed intake during the growing period reduces feed costs, delays sexual maturity and improves overall performance (Lewis, 1978).

B. Quantitative restriction

Variations in the quantitative method result from imposing the restriction at different times during the growing period and at different levels of ad libitum intake; including high, medium or low energy diets limiting the time of access to feed, or combining these with qualitative methods of restriction. This earlier research has

formed the basis for the sophisticated management methods now adopted by large breeder suppliers.

Limiting feed

Isaacks et al. (1960) carried out two long term experiments which included limiting breeder pullets to 30% of the ad libitum intake of a high energy diet fed during the eighth to twenty-first week of the growing period. In the first experiment there was a slight, but not significant improvement in hen-day production over the eight month laying period. However, in the second experiment, the results were more dramatic: 55% hen-day production for the restricted group versus 49% for the full fed control. In addition, feed intake in the former group was reduced by 25% during the growing period. Characteristically, with breeder pullet trials, mortality was high and ranged from 17 to 26% over the entire experiment.

The more recent experiments have recognized the reduced cost of medium and low energy grower diets and their advantage in further reducing growth rates. Britzman et al. (1965) reported a slight improvement in hen-day production, fertility and hatchability with a 30% restriction of a medium energy grower diet imposed from ten to twenty-one weeks of age. Other levels of restriction such as 5% (Peters et al., 1972), 10% (Lee et al.,1971b), 15% (Watson and Payne, 1972), 20% (Abbott and Couch, 1971) and 25% (Watson and Payne, 1972) of medium energy diets have resulted in variable (Table 1), but usually improved, performance over ad libitum feeding. Increasing the restriction beyond 30% (Powell and Gehle, 1977) to as high as 40% (Blair et al., 1976) was reported to cause

Table 1. Comparison of restriction methods when feeding broiler breeder pullets during the growing period.

Author		Restriction method	Age of restriction (wks)	Body weight (kg) 20-23 weeks	Body weight (kg) Final	Age at 50% production (days)	Mortality (%) Grower	Mortality (%) Overall	% Peak production	% Hen day
		Quantitative								
Isaacks et al.	(1960)	70% ad lib (high energy)	8-21	2.0	3.1	184	-	24.0	-	55.0
Harms et al.	(1968)	" " " (skip-a-day)	8-24	1.6	3.5	-	10.9	23.7	-	53.2
Schumaier, McGinnis	(1969)	" " " (skip-a-day)	8-23	2.5	3.6	-	-	-	-	59.6
Fuller et al.	(1970)	60% ad lib (low energy)	8-24	-	-	-	-	46.0	-	57.4
Fuller et al.	(1970)	70% ad lib (skip-a-day)	8-24	-	-	-	-	39.0	-	60.7
Lee et al.	(1971b)	10% ad lib	6-20	2.6	3.7	171	-	6.0	78.5	50.4
Lee et al.	(1971b)	70% ad lib	6-20	2.2	3.6	175	-	12.2	78.6	49.7
Peters et al.	(1972)	≈90% ad lib (low energy)	8-21	2.3	3.8	184	16.6	-	73.0	-
Blair et al.	(1976)	Breed recom. (r 70% ad lib)	2-22	2.3	3.1	189	5.5	-	-	≈57.0
Blair et al.	(1976)	-10% breed recom.	2-22	2.0	3.2	195	3.0	-	-	≈57.0
Blair et al.	(1976)	+10% breed recom.	2-22	2.6	3.2	183	6.0	-	-	≈58.0
Powell, Gehle	(1977)	≈60% ad lib	3-23	1.7	3.2	-	23.3	-	-	63.0
Hubbard Farms	(1978)	≈70% ad lib (skip-a-day)	3-23	1.9-2.1	3.3-3.4	185-195	-	≈10	82-85	67.0-70.0
		Fibre								
Isaacks et al.	(1960)	20% oat hulls	8-21	1.8	2.9	184	-	17.0	-	61.0
Waldroup et al.	(1966)	15% oat hulls	8-21	2.4	3.4	187	10.0	-	70.0	58.0
Summers et al.	(1967)	80% wheat bran	8-23	2.5	3.2	-	-	8.3	-	69.2
Summers et al.	(1967)	80% wheat shorts	8-23	2.8	3.3	-	-	14.5	-	67.8
Kondra et al.	(1974)	40% wheat straw	12-21	2.6	3.5	-	-	-	-	54.5
		Protein								
Waldroup et al.	(1966)	Low (≈10%)	8-21	2.0	3.4	197	8.0	-	-	55.1
Harms et al.	(1968)	Low (≈10%)	8-24	2.2	3.8	-	8.2	12.7	-	54.1
Fuller et al.	(1970)	Low (≈10%)	6-maturity	-	-	-	-	-	-	54.0
Lee et al.	(1971b)	Low lysine (3 levels)	6-20	2.2-2.6	3.7-3.9	169-180	-	13.3-29.1	72.7-76.1	47.7-51.2
Peters et al.	(1972)	Low lysine	8-21	2.1	3.8	196	19.7	-	68.0	-
Powell, Gehle	(1977)	Low tryptophan (3 levels)	3-23	2.7-3.2	3.5-3.6	-	2.2-5.0	-	-	41.0-52.0
		Other								
Isaacks et al.	(1960)	Ad lib	-	2.4	2.9	176	-	22.0	-	42.0
Waldroup et al.	(1966)	Ad lib	-	2.7	3.6	174	14.5	-	70.0	56.6
Schumaier, McGinnis	(1969)	Ad lib	-	3.5	3.9	-	-	-	-	47.9
Harms et al.	(1968)	Ad lib	-	2.9	3.9	-	12.0	15.7	-	51.2
Peters et al.	(1972)	Ad lib	-	2.6	3.9	181	2.2	-	67.0	-
Schumaier, McGinnis	(1969)	Limited time	8-23	3.4	3.6	-	-	-	-	58.6
Peters et al.	(1972)	Limited time	10-20	2.5	3.9	179	-	10.0	70.0	-
Cave	(1978)	Skip-a-day	7-20	2.2	3.3	196	1.4	-	-	50.1
Cave	(1978)	Whole grain (wheat-wheat)	7-20	1.8	3.3	201	8.0	-	-	47.8
Cave	(1978)	Whole grain (wheat-rye)	7-20	1.8	3.2	204	6.0	-	-	46.1

either poor performance (the former) or very high mortality (the latter).

Some of the problems encountered (social order, small versus big birds etc.) with limiting feed to pullets reared as a group in a pen have been overcome by combining quantitative restriction with a skip-a-day feeding programme. Feeding double the amount on an every other day basis ensures that even the least aggressive birds have access to feed, given adequate feeder space. This results in greater body weight uniformity and reduced mortality in the breeder flock as a whole (Lewis, 1978).

The first description of such a system was reported by Harms et al. (1968). They used low energy diets and a severe restriction (≃60% of ad libitum) from 14-24 weeks of age, fed on alternate days. A limited quantity of whole oats was given on the "no feed" days. A fifty per cent reduction in body weight and feed intake from the full fed control group during the growing period did not adversely affect layer performance. Mortality was higher for the skip-a-day group (23.7%) than the control group (15.7%). Schumaier and McGinnis (1969), using as a control a similar feeding method, found no differences in performance from their other restriction group (limited time of access to feed) in spite of a 27% decrease in feed intake.

Fuller et al. (1970) used the "skip-a-day" programme with oats fed on the off day and compared it to several other methods including and complicated by the effect of natural daylength and season. The skip-a-day group consistently performed better than the other groups. The authors determined that the improved performance was related to delay in sexual maturity and was unrelated to carcass fat. Age at sexual maturity was

defined as the time the first egg was laid and was remarkably late for the restricted groups. The authors recommend that pullets should not be brought into production until after twenty-six weeks.

Pym and Dillon (1972) suggested that optimal performance is obtained with a severe limitation (50% of ad libitum) of feed intake during the rearing period when fed on a skip-a-day basis from 10 to 24 weeks of age. They implied that the higher mortality observed during the grower period was compensated by a lower feed consumption and a higher production of hatchable eggs.

Very few papers have been published recently involving the quantitative, skip-a-day method and the industry has assumed the predominant role in both the research and promotion of this system. Lewis (1978) has summarized the latest recommendations of breeder suppliers as documented in their management guide books (i.e. Hubbard Breeder Pullet Manual, 1978). An earlier (begin at three weeks) and less severe (≈30% ad libitum) restriction scheme has been adopted as the most effective method of optimizing flock uniformity and productivity, while reducing feed costs and limiting losses due to mortality.

Limiting time of access to feed

All pullet rearing regimes investigated involve limiting indirectly access time to feed through lighting schemes which varied from eight to fourteen hours daily during the growing period. In addition, other methods have been tried. Blair (1972) and Lee et al. (1971a), who have reviewed the literature on the growth of breeding birds, have concluded that only very severe limitations (1-2 hours daily) are effective for reducing body weight. Birds, particularly of broiler stock, are highly

adaptable to such feeding regimes and increase their rate of consumption dramatically to compensate.

Schumaier and McGinnis (1969) compared a grower feeding schedule of 2 hours a day from 8-12 weeks and one hour a day from 13-23 weeks with the quantitative skip-a-day method. The authors concluded that limiting time effectively reduced body weight and had no effect on production, fertility, hatchability or egg weight. Feed intake was 27% higher for the limited time group.

Peters et al. (1972) fed a low energy, balanced ration for four hours a day from 10 to 12 weeks and for two hours a day from 12 to 20 weeks. Performance was better overall than a "restricted feed" group and resulted in a significant improvement on predicted income after cost analysis. Unfortunately, the authors emphasized the effectiveness of the quantitative group over the full fed control and failed to mention the limited time group in their discussion.

Skip-a-day feeding (ad libitum access to feed for 8 out of every 48 hours has received limited attention in the literature. Cave (1978) used this system from 6 to 20 weeks as a control and effectively maintained body weight within the recommendations of the breeder suppliers. Overall production was low (50% hen-housed) for the seven month layer period. Where problems exist in a practical situation with applying the quantitative method, the skip-a-day system would probably be adopted.

C. Qualitative restriction

The quantitative system is effective but labour intensive, requiring the continuous monitoring of flock weight and feed intake. Several methods of reducing excessive growth rates while maintaining

ad libitum feeding have been attempted and include: using grower diets that are low in protein or deficient in an essential amino acid, diluting diets with high fibre constituents or varying the quality of primary ingredients.

Altered protein quantity or quality

Waldroup et al. (1966) and Harms et al. (1968) reported feeding low protein (10%) grower diets from 8-21 weeks of age, resulting in a 10-25% reduction in body weight and feed intake from the full fed control (16-17% protein) groups. No significant differences were found among treatments in performance over the eight month layer period. Voitle and Wilson (1970) found that a 9.3% protein grower diet successfully delayed sexual maturity and maintained layer performance in relation to the other restriction methods. Body weight, however, exceeded the quantitative (skip-a-day) control, by 24% at twenty weeks of age.

Other authors have described poor performance from birds fed a low protein grower diet (Howes and Cottier, 1964; Abbott and Couch, 1971; Peters et al., 1972). Fuller et al. (1970), using a 10% protein diet from six weeks to maturity, found a marked reduction in hen-day production (54.0%) over the restricted energy (57.1%) or quantitative, skip-a-day (60.1%) treatments. Low protein diets, having had a variable effect on production, are not as effective as other means of restriction in reducing feed intake or preventing excessive growth rates.

An alternative method for feed restriction has been the use of rations that are low in one essential amino acid. Singsen et al. (1964) found that diets deficient in lysine and fed from 0 to 12 weeks (or longer) significantly reduced body weight, while having no adverse effects on

layer performance. Mortality during the whole trial was not influenced by grower diets. Abbott and Couch (1971) compared four levels of lysine deficient diets from 7 to 20 weeks and found that performance with the two least severe levels equaled that of the quantitative regime (80% of full fed).

Most reports have not been as positive as those described above. Voitle and Wilson (1970) successfully delayed sexual maturity compared to a control (full fed balanced ration) using a low lysine diet from 7 to 20 weeks of age. It was not, however, as effective as the other restriction methods. Three levels of low lysine diets (.63%, .50% and .40% lysine) fed from 0 to 12 weeks (Lee et al.,1971b) were found to be progressively more successful in delaying sexual maturity, exceeding either the 10% or 30% quantitative groups. Hen-day performance did not reflect this trend, with the minimaly deficient lysine group performing as well as the quantitative restricted group. Mortality (or forced culling) increased dramatically with the lysine deficient treatments due to a high incidence of rupture of the gastrocnemius tendon. The authors recommend, since only the least severe of the low lysine groups could be considered practically acceptable, that the quantitative method (with increased number of settable eggs) would be most effective.

Fuller et al. (1970) fed a low lysine starter (.63%) from 0 to 8 weeks, a low lysine (.49%) grower from 8 to 12 weeks and a balanced control ration to maturity. This regime, although superior to the full fed control group, was not as effective as either the quantitative or skip-a-day regimes.

The ad libitum feeding of a low lysine, low protein diet during the

growing period was the most effective method for delaying sexual maturity (196 days to 50% production) and reducing body weight at maturity (20% lower than control) (Peters et al., 1972). However, performance during the laying period for this diet was the poorest and mortality the highest of all restricted treatments. This suggests that predicting performance solely on the basis of delay in sexual maturity or reduction in twenty week body weight could be misleading.

A recent report (Powell and Gehle, 1977) compared the response to three levels of low tryptophan diets with a severe quantitative method (60% of ad libitum intake) as the control. When treatments were introduced at three weeks, performance of the control group was much better than that of the tryptophan deficient groups (63% hen-day versus 50% hen-day). The control group suffered from a high mortality of 23%. The authors stated that the overall performance of the birds on low tryptophan diets was "inferior" and the quantitative restriction of a balanced diet should be the preferred method. This conclusion is applicable to the more general theme of effectiveness of amino acid deficient diets for breeder pullet rearing.

Fibre diluted diets

Addition of poorly digested materials to a diet to limit basal intake and body weight gain has met with variable success. A consistent physiological adaptation is increased feed consumption, although not sufficient to maintain basal intake. Interest in its practical application to broiler breeder pullet rearing has been limited.

Isaacks et al. (1960) fed rations containing 44 or 58% oat hulls

(15 and 20% added crude fibre) from 9 to 21 weeks. At the higher dilution, body weight at maturity was lower than with the other restricted treatments, although delay in sexual maturity (age at 50% production) was as effective with the quantitative method (30% of ad libitum). Production over the thirty-six week laying period was higher for the high fibre group (61% hen-day) than the quantitative group (55%). High mortality for the low energy treatment during the growing phase was compensated for by much lower mortality (than the control group) during the breeding period. Feed intake increased dramatically - 50% in the growing period over the full fed group, and this trend still continued into the laying period (10% over the control).

Waldroup et al. (1966) compared a low protein and a high fibre (37% oat hulls) diet with the performance of a full fed medium energy diet from 8 to 24 weeks. The fibre diet was not as effective as the low protein diet in either reducing body weight or delaying maturity. Feed intake was 42% (high fibre) above the control group. No significant differences in mortality, egg production, fertility or hatchability were found.

Two experiments were conducted (Summers et al., 1967) to compare the effect on performance of an 80% wheat bran diet fed from 10 weeks (the first) or 8 weeks (the second) until 23 weeks to a full fed control diet. The second experiment also included a grower ration containing 80% wheat shorts. In both experiments the wheat bran diet resulted in a 15% reduction in body weight at maturity with a 40-50% increase in feed intake over the medium energy control. The wheat shorts had little effect on body weight, but increased intake by 10% over the control. During the

breeding period (27 to 55 weeks) the wheat bran group had higher % hen-day production than the control group. The slightly better performance of the wheat shorts was tempered by increased mortality. The authors suggested, in contradiction to prior research, that since sexual maturity was not delayed, the most important factor in improving performance was reducing live weight at "point of lay". They concluded that: "the combined results together with the superior feathering and quieter nature of the birds fed wheat bran, suggests that this growing treatment may have special merit". No further studies have been reported.

Ground wheat straw, included at 30%, was used to dilute a basal grower diet fed from 12 to 20 weeks (Kondra et al., 1974). The diet contained 20% crude fibre. Live weight was 13% lower than the full fed control by 21 weeks and basal feed intake declined by 25%. This is the first indication of improved basal nutrient utilization by inclusion of a fibre diluent. This could be related to the stage at which the diluent was introduced. Hen-day production was significantly improved in birds fed the wheat straw grower ration. In summation, it was speculated that: "anatomical and physiological adaptation in response to a lower nutrient density grower diet may have carried over into the layer period, hence the greater feed intake and hen-day production observed during the breeder period".

Waldroup et al. (1976) fed "ad libitum" from 6 to 22 weeks, a standard commercial ration diluted with graded levels (20, 30, 40 and 50%) of a high fibre source (ground rice hulls) to growing broiler breeder pullets. Although reduced weight gain was evident, the most severe dilution resulted in 22 week weights which exceeded the breeder's

recommendations by 20%. They concluded that levels in excess of 22% crude fibre must be used to successfully control body weight. No control treatment was included.

Other methods

Several other methods to improve breeder pullet performance have been attempted. The skip-a-day method applied during the breeder period and the debeaking of birds at 23 weeks have met with no success (Pepper et al., 1966). Manning and McGinnis (1979) have described preliminary experiments using low sodium grower diets and this might provide a practical alternative. No definitive results have yet been published.

The feeding of whole grain grower rations has recently been reported by Cave (1978). This experiment included the use of a 1:1 mixture of whole wheat and whole rye, whole wheat treatment and a medium energy mash diet fed on a skip-a-day basis (control). The whole grain diets, fed from 7 to 20 weeks, were supplemented with minerals and vitamins via the drinking water. Limited quantities of a commercial breeder ration were fed to all treatments from 21 weeks. Overall production was low throughout the breeding period (peak production was 65% for the control group) and poorest for the whole grain diets. The author emphasized the necessity of cost analysis when evaluating the relative merits of a feeding programme.

III. PHYSIOLOGICAL AND ANATOMICAL EFFECTS OF REARING METHODS

A. Gastrointestinal Development

1. General

Difficulty in interpretation of intestinal growth with respect to various dietary manipulations occurs particularly in cases where treatment also effects body weight gain. The confusion associated with body organ measurements is readily apparent in the literature. For example, some authors avoid the problem by simply not reporting the data. Conrad and Kuenzel (1978) found no differences in digestive tract measurements of male broilers on several meal feeding regimes. In spite of large differences in body weights and feed intake, no data on gastrointestinal measurements or statistical methods were given. Other authors have used sophisticated techniques. Cherry and Siegel (1978) reduced some variability inherent in organ weight analysis by an "arc sine transformation of the root of organ weights expressed as a percent of body weight".

Recently, papers have been published to obtain basic information about the normal growth of the G.I. tract. Crompton and Walters (1979) measured the dry weight of the alimentary tract of young cockerels fed commercial diets over the growing period and derived quadratic equations to relate organ development to body weight growth. Dror et al (1977) related the proportion (% of body weight) of different sections of the wet weight of the intestinal tract among light and heavy breeds of birds. Unfortunately, the inevitable genetic and environmental differences, prevent their general application as models for statistical analysis.

2. Dietary effects on gastrointestinal growth

Fibre

McCance (1974), in a paper describing the effect of age on weights and lengths of pigs' intestines, found that small intestine length was fully developed when pigs had reached only 25% of their mature weight. In his discussion he suggested that this rapid growth rate is independent of functional stimuli since, when the small intestine is surgically by-passed, growth rate is maintained. This is in contrast to the large intestine in pigs which develops in relation to a microbial stimulus responding to increased dietary fibre (i.e. post-weaning). A recent report by Petersson et al. (1979) studied the effects of sex, sire and diet deficiencies, including low energy, on the length, area and dry weight of the small intestine of pigs. Dietary changes were not found to influence the length of the small intestine; although with lower energy diets, the density (weight per metre) was significantly reduced.

Wildlife biologists have long recognized the apparent differences in gut sizes of wild fowl between the summer and winter seasons. Savory and Gentle (1976a, b) investigated the influence of various dietary changes to parallel seasonal changes in Japanese quail on food intake and gastro-intestinal growth. Fibrous foods, predominating during the winter months, have been associated with the development of increased gut tissue. Their initial experiment (Savory and Gentle, 1976a) utilized standard quail grower diets diluted using two fibre sources: oak sawdust and cellulose, at 20% and 40% of the ration. At 10 and 20 weeks of age the birds, separated by sex, were sampled for measurement of the G.I. tract. The authors used covariance analysis to eliminate differences due to body

weight. The high fibre birds were significantly smaller than those fed conventional diets. The authors concluded that the significant increases in gut size were more related to level of intake (reinforced by age and sex effects) than the inclusion of fibre "per se". Differences found in the small intestine were minimal, while those found in the colorectum, ventriculus and caecum were highly significant ($P \leq .001$).

In a follow-up experiment (Savory and Gentle, 1976b) an effort was made to establish the rate at which gastrointestinal tissue could adapt to changes in diet density. Adjustments for body weight differences were again made by covariance analysis. The authors reported that increases in gut dimensions were reversible, the adjustment being complete in three to four weeks. They stated that: "the elasticity of the digestive system might permit it to maintain the minimum size necessary for optimal digestion".

Kondra et al. (1974) fed low (≈8%) and high (≈20%) crude fibre diets, using wheat straw as a diluent, to meat and egg-type commercial pullets from 12 weeks to maturity. At 20 weeks of age they were sampled for detailed anatomical measurement and all analyses were performed using the "Ratio Method" (grams or centimetres of tissue per kilogram body weight). Significant increases in the weight and length of both the small and large intestine were observed with high fibre feeding. In addition, with this diet, liver and gall bladder weights were significantly smaller, while the ventriculus and pancreas were larger. The authors concluded that these differences might reflect an increased capacity of the digestive system to adapt to lower nutrient concentration.

Hakansson et al. (1978) and Clason et al. (1978) extensively monitored the growth of the G.I. tract with age and body weight of chicks fed

rations with differing metabolizable energies. The diets were adjusted by replacing corn and wheat with oats and barley. A notable observation was that increases in length of the tract occurred in relation to age. Therefore, at corresponding body weights, birds fed a lower energy diet had longer intestines than those fed diets at a higher nutrient density. As the birds reached maturity these differences became less noticeable. Much larger ventriculi were observed with the high fibre diets on both an age and a body weight basis. Comparison of treatment effects on organ development were done by simple regression analysis.

Younoszai et al. (1978) described experiments in which young growing rats, fed nutritionally adequate purified or semi-purified rations, were compared to rats fed a conventional ration. Analysis of the growth of the intestinal tract was made by relating wet weights, dry weights or wet weights expressed as a ratio to body weight. The purified diet, containing no source of fibre, when fed to rats resulted in animals which had the smallest body weight and organ development. The group fed the conventional ration (3.5% fibre) grew at a faster rate and had the largest caecum and small intestine, this being consistent for all three methods of analysis. The most dramatic effect between the no fibre diet and the others containing fibre was seen in the colon where the wet weights with the 5% crude fibre treatments were increased 20% over the no fibre group. No effects of various carbohydrate, protein or fat sources were detectable. Only the diets containing crude fibre or cellulose had a significant effect.

Feed restriction

Lee et al.(1971a), in a review of restriction methods for egg-type pullets, emphasized the lack of information available on the physiological

and anatomical effects of such regimes. They measured intestine, liver and ventriculus weight of birds fed at either of two levels (90 or 70% of full fed control). No differences were found in organ weights analyzed using the "Ratio Method".

The effects of food restriction (70% of ad libitum from 3-21 weeks) in chickens on ventriculus, liver, pancreas and abdominal fat was studied by Hollands et al. (1965). Recognizing the difficulty in interpreting results where treatment effects on body weight must be separated from those on organ weight, the authors used regression analysis on either transformed or non-transformed data. Any transformations gave better approximations to the normal distribution. Where similar and significant regressions between treatments existed, organ weights were compared to a common body weight after adjustment by covariance analysis. Using this method a significant increase in ventriculus and pancreas was observed in the restricted regime. This was attributed to these birds eating litter to compensate for reduced feed availability. Liver size was found to be directly related to caloric intake and therefore significantly smaller with the restricted group. They also had significantly less abdominal fat.

Rye

Antoniou (1980) measured the size (both length and weight) of caeca and small intestine of chicks fed rye or rye pentosans and concluded that a well defined increase in length (cm/unit body weight) was associated with these diets when compared to control diets. Significant ($P \leq .05$) growth effects with the various diets fed were also observed.

Support for an effect of hemicellulose on gut tissue was reported recently by Brown et al. (1979), who found that pectins (a water soluble polymer of galacturonic acid) when fed to rats at 18% of the diet, resulted in a significant increase over the control diet in length (mm) and wet weight (mg per mm of tissue) of the small bowel. The differences described however, were limited to the mid-jejunum, since the length in the other four sections was the same or slightly shorter for the pectin group. The wet weights of the terminal ileum and caecum plus colon were also larger for the pectin group. The authors determined that these differences were due to increased muscle layer and mucosal thickness which might be related to an adaptive increase in absorptive surface area.

3. Statistical methods

The problem of the relationship between organ weight and body weight has been reviewed by Burger et al. (1962). They discussed the necessity of establishing a thorough understanding of the nature of organ weight variability and suggested that simple methods to remove the effects of body weight might be "naive" and "misleading". The most common method, often referred to as the "Ratio Method", expresses organ weight, for example, as grams per 100 grams body weight. Their "preconditions" for the simple application of the "Ratio Method" are that the estimate of the intercept of the linear regression of organ weight on body weight approximate zero and the variance of the dependent variable (organ weight) be proportional to the square of the independent variable (body weight). The authors concluded that whenever significant body weight and organ weight relationships exist, linear regression, with necessary transformations to reduce variance, should be used.

B. Rate of passage

Rate of passage through the G.I. tract has a major influence on the nutrition of the chick because, it determines the length of time during which nutrients may be absorbed, it affects the type and quantity of microflora in the lower gut and it could have a regulatory effect on feed intake (Tuckey et al., 1958).

Information concerning the movement of material through the gut is becoming more abundant. Hunt et al. (1978) describes two sets of receptors in the duodenal mucosa, one responding to osmotic stimuli and the other to altered surface tension due to soap formation during fat digestion. The rate of gastric emptying is proportional to the energy per millimetre of gastric contents - the higher the energy density, the slower the rate. Therefore high fibre diets would deliver a low osmolality chyme to the duodenum resulting in faster rates of emptying.

Bjornhag and Sperber (1977) studied the relative transport of food in the G.I. tract of several avian species using labelled (^{14}C) and unlabelled (cold) polyethylene glycol as water-soluble reference markers. The distribution of particulate matter and the relative concentrations of the marker in various parts of the intestine led them to the conclusion that more digestible material moves more slowly relative to the less digestible particles. Thus, foods containing large amounts of plant fibre would pass through the tract relatively quickly permitting greater feed input. Mitchell and Eastwood (1978), in a review of research on dietary fibres' influence on colon function, described experiments which used dual markers, one water soluble and one insoluble, which clearly demonstrated that "solids and the associated gel water travelled faster through the gut than liquids, indicating streaming of solid and liquid

phases".

It is apparent from these papers that a primary result of increased dietary fibre should be a decrease in transit time. Extensive research involving humans, however, has met with conflicting evidence, some of which has been reviewed by Spiller and Amen (1972). Although various sources of plant fibre have been used as laxative agents, the more direct relationship between inclusion of fibre, fecal bulk and transit time has been difficult to characterize. A recent review (Spiller et al., 1978) describes experiments confirming the inverse relationship of transit time with fibre intake up to a maximal "critical fecal weight". Presuming a short transit time is beneficial for humans, a direct correlation between fibre intake and fecal output could be established and an appropriate nutritional adjustment recommended.

Cummings et al. (1976) have described some of the important criteria for using markers in rate of passage studies. The marker must be non-absorbable, non-toxic and reasonably easy to measure. It should not alter gut metabolism and must mimic the natural dietary residue of the material to be studied. The authors used radioopaque pellets which were readily identifiable by x-ray of the feces. These pellets were designed to have the same specific gravity as the material in their diets. Particle size was not mentioned.

Several methods for measuring rate of passage in birds have been reported. The effect of different fibre sources and procedures has contributed to conflicting results. Tuckey et al. (1958) used an aqueous ferric oxide indicator administered orally to chicks which were fed diets containing varying levels of fat or NPPF (oat hulls). Passage

rate was determined by recording the time of first demarkation of the marker in the feces. Although the addition of fibre had no significant effect, inclusion of 10% animal fat slowed "the rate of passage". The authors suggested that the form of fibre (fine or coarse grind) was more important than the level in the diet "as regards the effect on passage time". In addition they determined that environmental changes radically altered rates of passage and recommended that in studies such as these there should be minimal interference in the animal's normal routine.

The problems associated with measuring first appearance of a marker in the feces has been borne out in studies by Cherry and Siegel (1978). Using a ferric oxide marker encapsulated in gelatin with diets fed to 8 week old chicks, the authors related time to first appearance to the total pattern of marker excretion. Time to first appearance would be a reliable indicator if recovery followed a normal distribution. This was clearly not the case in their data and time to first appearance would have given erroneous results.

Another important water soluble marker, ^{14}C-polyethylene glycol, was used by Coates et al. (1977) to measure rates of passage in quail fed a purified diet with or without addition of soya protein. Recovery, after 8 hours, of 16.4% of the label in the control diet and 7.1% of the label in the soya protein diet led the authors to the conclusion that the longer transit time for the latter diet was required for its complete digestion.

Jensen et al. (1962) compared the rate of passage of pelleted and non-pelleted rations fed to growing chickens. A chromium oxide (water

insoluble) pulse was given after overnight food removal and the rate of chromium recovery was followed at one hour intervals for nine hours. The main advantage described for this technique was that the pattern of marker excretion over a period of time is measured, rather than just first appearance. No "obvious" differences from the control were observed, although the authors felt that collecting at one hour intervals impaired the sensitivity of the study.

Sibbald (1979), to further substantiate his bioassay for true metabolizable energy (TME), which assumes that feed passes through the alimentary tract within 24 hours, measured rate of passage of feed through the adult rooster. After feeding four diets, including a high fibre diet, for 90 hours, the feed was removed and excreta were collected quantitatively at established intervals for 52 hours. Cumulative dry matter excretion after 10 hours from feed removal was twice that for the high fibre group when compared to the other three diets. After 10 hours no differences in the rate of dry matter excretion were detected and Sibbald concluded that these excreta were of endogenous or metabolic origin. In another experiment, (Sibbald, 1979) force feeding different quantities of wheat bran indicated that rates of passage are also affected by level of feed intake. Increases in passage time with higher feed intake were obvious during the active period; but these differences became minimal with low activity during the dark period. Thus rate of passage is determined by feed quality and quantity, while being influenced by the behavioural state of the bird.

MATERIALS AND METHODS

I. PRELIMINARY STUDIES - THE EFFECT OF DIETARY FIBRE ON GROWTH AND GASTROINTESTINAL DEVELOPMENT

These initial studies were undertaken to establish the basic effects of fibre dilution on growth, total and basal feed conversion and nutrient retention. A specific aim was to determine the level of dilution that would give a significant reduction in growth rate so that this could be applied to the design of the broiler breeder grower experiment. In addition, the monitoring of adaptive responses to fibre feeding in the gastrointestinal tract would provide general information relating to overall digestive and absorptive capacity. While attempting to analyze the gut size data it was recognized that fundamental information was lacking regarding the effects of age and body weight on organ development.

A. Cockerel study 1 - mash diets

Four day old SCWL cockerel chicks were placed (15 birds/pen) into twenty-four pens of an electrically heated, thermostatically controlled Petersime battery brooder which had raised wire floors. Continuous lighting was maintained throughout the experiment. For the first seven days all birds were fed the basal diet (Table 2). At this time all chicks were wingbanded and the eight treatments (Table 2), including two basal groups were assigned randomly to the twenty-four pens. Feed consumption, group body weights and mortality were taken and recorded weekly for the next four weeks. Feed efficiency was calculated over the four week experimental period by relating total feed and basal feed

Table 2.% Composition of fibre cockerel diets

	Basal Control	Cellulose (%)			Wood aspen (%)		
		5	10	15	5	10	15
Treatment No.	1, 8	2	3	4	5	6	7
Wheat	77.7	73.8	69.9	66.1	73.8	69.9	66.1
Cellulose[3]	-	5.0	10	15	-	-	-
Steamed aspen[4]	-	-	-	-	5	10	15.0
Soybean meal	11.0	10.5	9.9	9.4	10.5	9.9	9.4
Fishmeal	5.0	4.8	4.5	4.3	4.8	4.5	4.3
Soy oil	.9	.9	.8	.8	.9	.8	.8
Alfalfa meal	1.0	1.0	.9	.9	1.0	.9	.9
Dicalcium phosphate	1.7	1.6	1.5	1.4	1.6	1.5	1.4
Limestone	.9	.9	.8	.8	.9	.8	.8
Vitamin mix[1]	1.3	1.2	1.2	1.1	1.2	1.2	1.1
Mineral mix[2]	.5	.5	.5	.4	.5	.5	.4
Analysis (as fed)							
Protein	19.4	18.2	17.2	16.3	18.3	16.9	16.4
Crude fat	3.3	2.8	2.5	2.4	2.9	2.8	2.9
Crude fibre	2.9	5.8	8.6	13.1	5.0	8.3	10.3
Calcium	1.1	.9	.8	.8	.9	.8	.9
ME (kcal/kg) calculated	2900.0	2755.0	2480.0	2110.0	2755.0	2480.0	2110.0

[1]The vitamin mix supplies per kilogram of premix: Vit. A - 826,000 I.U.; Vit. D_3 - 88,000 I.U.; Vit. E - 550 I.U.; Vit. B_{12} - 1.1 mg; riboflavin - 220 mg; calcium pantothenate - 440 mg; niacin - 1.1 gm; choline - 11 gm; methionine, D.L. - 50 gm; santoquin - 12.5 gm; animal tallow - 100 gm.

[2]The mineral mix supplies per kilogram premix: iodized NaCl - 480 gm; manganese (oxide) - 16.5 gm; Zn (oxide) - 5.5 gm.

[3]Alpha-floc (a cellulose product) supplied by Brown Company, New York.

[4]Supplied by Stake Technology, Ottawa, Ontario.

(total feed intake minus fibre intake) intake on a per unit body weight gain basis.

At the end of each week, two birds per pen were sacrificed (cervical dislocation) after starving overnight, and their gastrointestinal organs were measured. The abdominal and thoracic cavities were exposed and the total length of the alimentary tract removed. The proventriculus and ventriculus were isolated, sliced open, rinsed, blotted dry and weighed. The liver, gall bladder and pancreas were removed and weighed. Care was taken to avoid stretching of the intestines while uncoiling and taking length measurements. The small intestine was arbitrarily divided into the following sections: the duodenum from the ventriculus to immediately distal to the bile ducts; the jejunum sectioned at the yolk sac; and the ileum from the yolk sac to the ileal-caecal junction. The caeca, removed from the colon, were placed end to end before measurements were taken. All segments were then gently squeezed to remove residual digesta and weighed. Further analysis of the data is described in detail in the statistics procedures section.

During the third week, and after a two day adaptation to the same experimental diets supplemented with 0.3% chromium oxide, a three day excreta collection was undertaken. Excreta samples were quantitatively freeze dried and feed and feces were analyzed for crude protein, ether extract, crude fibre, calcium and phosphorus according to methods described in AOAC (1975). Retention was determined using the standard procedure (Williams et al., 1962).

B. Cockerel study 2 - pelleted diets

Some problems encountered with the high fibre mash diets (particularly feed spillage and sorting) could be alleviated by pelleting the rations. This experiment followed the same procedure described for cockerel study 1 (same number of birds) with two exceptions:

1) All diets (Table 2) were pelleted.

2) G.I. tract measurements were taken on the second and third week after introduction of experimental diets.

C. Cockerel study 3 - effect of age and body weight on the development of the G.I. tract

One hundred SCWL cockerels, one day old, were placed in a floor pen (4.3 metres by 1.5 metres) and fed the wheat starter and grower rations (Table 3) used in the broiler breeder trial. They were exposed to an 8 hour per day lighting scheme. At weeks 0, 1, 2, 3, 4, 5, 7, 9, 11 and 14, ten birds were removed for measurement of the gastrointestinal tract. This procedure followed that described in cockerel study 1. The data were collected and plotted using the scattergram programme of the SPSS (Nie et al., 1975) computer package.

II. BROILER BREEDER STUDIES

A. Study 1 - major growth and egg production trial

The objective of this study was to evaluate the effectiveness of a broiler breeder grower diet formulated on the basis of the findings in the cockerel trial and of reports in the literature concerning optimal restrictions in feed intake. Wheat straw was used as the fibre diluent because it was readily available and had been effective in a previous

Table 3. % Composition of broiler breeder starter and grower diets

	Starter diets			Grower diets			
	Wheat	Fibre (10%)	Rye	Wheat	Fibre (20%)	Fibre (30%)	Rye
Wheat	74.5	66.6	34.5	85.0	68.0	59.5	45.0
Rye	-	-	40.0	-	-	-	40.0
Ground wheat straw	-	10.0	-	-	20.0	30.0	-
Soybean meal (44%)	14.5	13.1	14.5	4.0	3.2	2.8	4.0
Fishmeal (65%)	5.0	4.5	5.0	2.0	1.6	1.4	2.0
Soy oil	1.0	.9	1.0	1.0	.8	.7	1.0
Alfalfa meal (17%)	1.5	1.0	1.5	4.0	2.6	1.6	4.0
Calcium phosphate	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Limestone	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Vitamin mix[1]	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mineral mix[2]	.5	.5	.5	.5	.5	.5	.5
Analysis (as fed)							
Protein (%)	21.8	19.2	21.4	17.4	14.7	12.7	16.3
Fat (%)	3.0	2.8	3.0	2.0	1.8	1.9	2.5
Crude fibre (%)	2.5	7.7	2.8	4.4	13.9	20.0	4.2
Ash (%)	5.9	6.3	5.7	-	-	-	-
Calcium (%)	1.0	1.0	1.0	1.1	1.1	1.0	1.0
Phosphorus (%)	.7	.8	.8	.8	.7	.7	.8
ME energy (kcal/kg) calculated	2900.0	2600.0	2800.0	2900.0	2400.0	2050.0	2800.0

[1] As described in Table 2.

[2] As described in Table 2.

experiment (Kondra et al., 1974). The rye diet was included as a small contribution to a much larger cooperative study assessing the feeding value of rye grain in animal production.

A broiler breeder strain would have been preferred for these studies. Overall budget restraints encouraged the use of a more economical bird as a model for the parent stock. A commercial broiler strain (Hubbard) was selected. The rapid growth rates exhibited by broilers could permit an optimal evaluation of the effectiveness of the experimental regimes to control weight gain during the growing period.

1. Grower phase

Seven hundred and thirty-five commercial pullet chicks of a meat type strain were wingbanded at one day of age and allotted randomly in groups of thirty-five to each of twenty-one floor pens; each pen being 4.3 metres long by 1.5 metres wide. Supplemental heat was supplied by heat lamps under a canopy brooder. Light was provided for twenty-four hours daily during the first week but reduced to eight hours for the remainder of the growing period. Fifty male chicks of the same strain (Hubbard) were placed in a separate pen. All birds were full fed the wheat starter diet (Table 3) during the first week. The males continued on a full fed wheat starter and grower diet for the entire grower period.

Figure 1 (a) summarizes the feeding programme during the growing phase. At one week of age the three starter diets (Table 3) were assigned consecutively to the twenty-one pens. Grower diets, with the fibre included at 20%, were introduced at four weeks of age and the following week the wheat and rye fed birds were placed on a skip-a-day (feed available 8

Figure 1a. Outline of diets and feeding schedule during the growing period for Broiler Breeder Study #1

Weeks	# of pens	Diet	Feeding regime
0-1	21	Wheat starter	Full fed
1-4	7	Wheat starter	Full fed
	7	Rye starter	Full fed
	7	Fibre (10%) starter	Full fed
4-5	7	Wheat grower	Full fed
	7	Rye grower	Full fed
	7	Fibre (20%) grower	Full fed
5-6	7	Wheat grower	Skip-a-day
	7	Rye grower	Skip-a-day
	7	Fibre (20%) grower	Full fed
6-22	5	Wheat grower	Skip-a-day
	7	Rye grower	Skip-a-day
	5	Fibre (30%) grower	Full fed
	4	Wheat grower	Full fed

out of every 48 hours) programme. At six weeks the fibre diet was formulated to include 30% wheat straw (Table 3).

Inconclusive results observed with the gastrointestinal sampling at six weeks made the creation of a fourth treatment desirable. Two pens from the restricted (skip-a-day) wheat diet and two from the fibre diet were placed on a full fed regime with the wheat based, control diet. The four grower treatments, illustrated in Figure 1b, were continued until the termination of the grower period at 20 weeks.

Bi-weekly feed consumption and body weights were recorded. Detailed anatomical measurements of the G.I. tract were taken on a random selection of two birds per pen at 6 and 15 weeks into the trial. A shortage of birds as a result of poor sexing (more males than anticipated) and a major disease outbreak at three weeks, necessitated the use of culled birds for the twenty week gastrointestinal sampling. All gastrointestinal measurements were taken as described in Cockerel Study 1. Body conformation was evaluated at twenty-two weeks by randomly selecting 2 birds per pen and measuring with a tape ruler the point of maximal abdominal circumference and the length of the keel, tibia and total body (1st thoracic vertebrae to the tip of the pygostyle). Mortality records were maintained and when necessary the cause of death was determined by a veterinarian.

2. Layer phase

At the end of twenty-two weeks eighty birds, selected from each grower treatment were placed on the same wheat, oat-based layer diet (Table 4), except for the rye group which was continued on a 40% rye diet formulated (Table 4) to meet the layer requirements. All pens were fed

Table 4. % Composition of broiler breeder layer diets

	Wheat:oats	Rye:oats
Wheat	40.0	-
Oats	38.0	38.0
Rye	-	40.0
Soybean meal (44%)	10.0	10.0
Fish meal	2.5	2.5
Tallow	1.0	1.0
Dicalcium phosphate	1.0	1.0
Oyster shell	3.0	3.0
Limestone	3.0	3.0
Vitamin mix[1]	1.0	1.0
Mineral mix[2]	.5	.5
Actual analysis		
Protein	15.8	15.1
Fat	3.1	2.9
Crude fibre	8.3	7.8
Calcium	2.7	2.8
Phosphorus	.7	.6
ME energy (kcal/kg) calculated	2600.0	2500.0

[1]The vitamin mix supplies per kilogram of ration: Vit. A - 8,260 I.U.; Vit. D_3 - 880 I.U.; Vit. E - 5.5 I.U.; Vit. B_{12} - 11 mg; menadione - 1.1 mg; pen-strep - 1 gm; santoquin - 125 mg; riboflavin - 5.5 mg; calcium pantothenate - 11.0 mg; niacin - 27.5 mg; choline - 275 mg; methionine, D.L. - 5 gm; amprol - .5 gm.

[2]The mineral premix supplies per kilogram of ration: iodized NaCl - 4.7 gm; manganese (oxide) - 330 mg; zinc (oxide) - 14.3 mg; iron (sulphate $7H_2O$) - 308 mg; copper (sulphate $5H_2O$) - 25.3 mg.

on the basis of allotting 150 grams of feed per bird per day (Figure 1b). Egg production was recorded daily and monthly averages were plotted for each treatment. All birds were weighed at the end of each four week period. During a three day period each month all eggs were collected and weighed. The roosters maintained in the extra pen during the growing period were introduced to the breeding pens (2 males/16 females) at the beginning of month 2 and rotated among the pens every 7 days. In the second and third month of production the three day collection of eggs were set for determination of fertility and hatchability.

B. Study 2 - effect of rearing regimes on the early nutrition and physiology of the broiler chick

This experiment was designed to study the effects of the rearing regimes used in the previous study on growth, feed utilization, nutrient retention and rate of passage. To maximize the response, the treatments were imposed without an adaptation period and at a very early age. To facilitate feeding all diets were pelleted and crumbled.

Four hundred and eighty female broiler chicks (Hubbard), one day old, were wingbanded and weighed in groups of thirty. Each group was placed into one of sixteen floor pens, brooded under a heat lamp and fed a commercial starter diet until one week of age. Full light was provided during this period. On the eighth day the four treatments (Table 5) were assigned alternately to the sixteen pens and light was reduced to 8 hours daily. Growth and feed intake were recorded weekly. Any mortalities were noted. The experiment was terminated at 7 weeks.

During the third week 9 birds from each of the four treatments and weighing within 1% of the treatment mean were placed into a Petersime

Figure 1b. Broiler breeder grower and layer treatments

Grower ration	Breeder ration
1. Full fed wheat	Wheat, oat-based (fed at 150 grams/bird/day)
2. Full fed fibre (30% wheat straw)	
3. Restricted[a] wheat	
4. Restricted[a] rye	Rye, oat-based (fed at 150 grams/bird/day)

[a]Skip-a-day feeding.

Table 5. % Composition of diets for broiler breeder study #2

	Full fed wheat & restricted wheat[4]	Full fed Fibre[3,4]	Restricted Rye[4]
Wheat	85.0	59.5	45.0
Rye	-	-	40.0
Ground wheat straw	-	30.0	-
Soybean meal (48%)	4.0	2.8	4.0
Fish meal (65%)	2.0	1.4	2.0
Soy oil	1.0	.7	1.0
Alfalfa meal (17%)	4.0	1.6	4.0
Calcium phosphate	1.0	1.0	1.0
Limestone	1.5	1.5	1.5
Vitamin mix[1]	1.0	1.0	1.0
Mineral mix[2]	.5	.5	.5
Actual analysis			
Protein	14.4	11.6	14.6
Fat	3.3	2.7	3.6
Crude fibre	4.5	19.0	5.0
Ash	5.9	6.9	6.4
ME (kcal/kg) calculated	2900.0	2050.0	2800.0
Calcium (%) calculated	1.0	1.0	1.0
Phosphorus (%) calculated	.7	.7	.7

[1]As described in Table 2.

[2]As described in Table 2.

[3]All fibre diets were reground to obtain uniformity of fibre material throughout the mash.

[4]All diets were pelleted and crumbled.

battery brooder (3 birds per cage unit) that had been adapted for metabolic studies. These birds were maintained on their same diets, lighting and feeding schedule. A six day total excreta collection was begun on an "on feed" day in the fourth week. Excreta samples were freeze dried and feed and feces analyzed for crude protein, ether extract, crude fibre, calcium, magnesium, phosphorus, sodium and potassium according to the methods described in AOAC, 1975.

Rate of passage was measured in the fifth week according to a method modified slightly from that described by Jensen et al., 1962. The diets were made with addition of 2% chromic oxide, pelleted and then crumbled. After overnight food removal the birds were exposed to the marker diets for 1½ hours. Feed intake was recorded and the unmarked diets were returned for the remainder of the feeding period. Feed intake was again recorded. Total excreta were collected at one hour intervals for 8 hours beginning two hours after introduction of the marker diet. Subsequent samples were taken at ten, twelve and twenty-four hours. Additional samples were collected at 48 hours with the restricted birds. All samples were quantitatively freeze dried and feed and excreta were analyzed for total chromic oxide content. Percent (of total chromic oxide intake) cumulative recovery was plotted against the time after introduction of the marker feed.

III. CHEMICAL ANALYSIS

Determinations of dry matter, crude protein, ether extract, energy, crude fibre and ash were made according to the Official Methods of Analysis of the Association of Official Chemists, 12th edition, 1975.

Similarly, minerals were analyzed using their methods in conjunction with those in Analytical Methods for Atomic Absorption Spectrophotometry (1973).

IV. STATISTICAL PROCEDURES

A. General

The data were analyzed by analysis of variance as described by Snedecor and Cochran (1967) and multiple comparisons among means were made using Tukey's Test (Steele and Torrie, 1960). All analyses of variance are given in the appendix section.

B. Gastrointestinal measurements

All measurements were compared using standard analysis of variance techniques (Snedecor and Cochran, 1967) on either unadjusted (raw data) or adjusted values. Adjustments were made using the "Ratio Method" which involved expressing the data per kilogram body weight.

The data from the two cockerel trials (1 and 2) were also subjected to regression analysis as described by Hollands et al. (1965). Where similar and significant slopes existed the treatments were compared using covariance analysis with body weight as the covariate. A comprehensive multiple regression procedure (Kim and Kohout, 1975) which included the use of dummy variables facilitated the complete characterization of the data. A more detailed description of the analysis is given in Appendix B.

RESULTS

I. COCKEREL STUDIES

A. Study I - mash diets

1. Growth and feed intake

Table 6 illustrates the effect of inclusion of graded levels of two fibre sources (wood aspen and cellulose) in mash diets on feed intake and feed efficiency. Addition of fibre beyond 5% caused a significant ($P \leq .01$) reduction in body weight gain, a tendency towards reduced feed intake and greater feed to gain ratios on an as fed basis. Although no effect of level was observed when feed efficiency was compared as basal intake, the cellulose diet was not as well utilized ($P \leq .05$) as the wood aspen diets.

2. Nutrient retention

The predictable decrease in dry matter retention ($P \leq .01$) and increased crude fibre retention ($P \leq .01$) with the greater levels of included fibre is shown in Table 7. A notable observation was the slight, although, not significant improvement in dry matter retention at the 5% level, as well as a significantly ($P \leq .01$) higher phosphorus retention.

A significant reduction ($P \leq .01$) in calcium retention with the cellulose diets relative to the wood aspen diets was observed. In addition, there was a trend towards lower calcium and fat retention at higher levels of dietary fibre.

Table 6. Effect of fibre type and fibre level on growth and feed intake of cockerels fed non-pelleted diets.

		Weight gain (grams)	Feed intake (grams)	Feed/gain ratios	
				As fed	Basal
				(g feed/g gain)	
Fibre type	Cellulose	233.0	602.2	2.57b[2]	2.31b
	Aspen	242.7	603.2	2.49a	2.24a
	S.E.	4.89	10.40	.03	.03
Fibre level	0	270.0C[1]	618.0	2.29A	2.29
	5	259.5BC	619.0	2.40A	2.28
	10	242.5B	606.0	2.50A	2.24
	15	211.5A	572.0	2.71B	2.30
	S.E.	6.92	14.70	.04	.04

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 7. Effect of fibre type and fibre level on nutrient retention (%) of cockerels fed non-pelleted diets.

		Dry matter	Nitrogen	Ether extract	Crude fibre	Calcium	Phosphorus
Fibre type	Cellulose	59.54	39.03	66.17	-14.30b[2]	38.61A	21.34
	Aspen	61.77	45.29	72.75	- 4.63a	51.16B	24.12
	S.E.	1.04	2.67	2.35	1.89	2.44	1.40
Fibre level	0	64.54B[1]	44.49	75.12	-42.48D	51.40	20.50AB
	5	65.47B	48.55	73.33	-17.24C	49.01	28.79C
	10	58.65A	44.35	68.29	-13.11B	45.07	17.05A
	15	53.97A	33.37	69.48	1.96A	40.59	22.36BC
	S.E.	1.47	3.78	3.32	2.68	3.45	1.98

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

3. Gastrointestinal tract measurements

Significant differences in gastrointestinal measurements between fibre levels using the unadjusted method (Table 8) were limited to liver weight ($P \leq .01$), jejunum length ($P \leq .01$) and jejunum weight ($P \leq .01$), and ileum weight ($P \leq .01$). The only difference with fibre type occurred with the caecum, where the cellulose group had a significantly ($P \leq .01$) shorter length than the wood aspen group.

When these organs were compared using the "Ratio Method" (Table 9) significant differences ($P \leq .01$) between fibre levels were noted for all measurements except liver, gall bladder and caecum weights. In all cases the larger organ weight, length or density occurred with the high fibre group, this group also having the lowest body weight.

The third method of analysis was the regression method. Table 10 lists the organs which were compared using covariance analysis (to body weight) when significantly different, non-interacting regression on fibre level was observed. The detailed statistical analysis is described in Materials and Methods and detailed in Appendix Table 5. Increased levels of added fibre resulted in increased ventriculus and colon weight ($P \leq .01$), and jejunum, ileum and colon density ($P \leq .05$).

B. Study 2 - pelleted diets

1. Growth and feed intake

The overall performance of the birds fed the pelleted diets was improved over those on the mash diets. For example, the control group after three weeks on the pelleted diets gained 276.3 grams (Table 11), while those on the non-pelleted diets, after four weeks, gained only

Table 8. Effect of week, fibre type and fibre level on means of unadjusted G.I. tract measurements in cockerels fed non-pelleted diets

	Liver weight gm	Gall blad. weight gm	Pancreas weight gm	Provent. weight gm	Ventric. weight gm	Duodenum Length cm	Duodenum Weight gm	Duodenum Density mg/cm	Jejunum Length cm	Jejunum Weight gm	Jejunum Density mg/cm	Ileum Length cm	Ileum Weight gm	Ileum Density mg/cm	Colon Length cm	Colon Weight gm	Colon Density mg/cm	Caecum Length cm	Caecum Weight gm	Caecum Density mg/cm	Body weight gm
Week																					
2	3.18A[1]	.20A	.66A	.94A	4.52A	14.31A	1.73A	120.61A	30.36A	2.09A	68.71A	30.31A	1.44A	47.61A	4.47A	.39A	87.05A	13.64A	.82A	70.40A	112.7A
3	5.20B	.29B	.95B	1.33B	6.37B	15.69B	2.10B	134.29B	33.70B	2.83B	84.35B	34.75B	2.14B	61.66B	5.03B	.55B	110.66B	16.52B	1.35B	81.52A	186.1B
4	8.63C	.51C	1.50C	2.07C	10.27C	17.49C	2.78C	159.08C	37.94C	4.11C	108.43C	40.78C	3.38C	82.73C	5.75C	.93C	162.36C	20.54C	2.09C	101.91B	338.4C
Fibre type																					
Cellulose	5.63	.33	1.02	1.43	6.92	15.70	2.18	137.78	33.57	2.99	87.43	35.24	2.34	64.42	5.09	.63	120.91	16.56A	1.37	86.60	211.3
Aspen	5.71	.33	1.05	1.47	7.18	15.96	2.23	138.20	34.43	3.04	86.90	35.32	2.30	63.59	5.07	.62	119.13	17.24B	1.48	82.62	213.4
% Fibre level																					
0	5.95C	.32	1.02	1.48	6.79	15.99	2.25	139.31	34.62B	3.06B	87.31	35.86	2.43B	65.98	5.14	.63	118.80	17.08	1.43	81.19	230.9D
5	5.99C	.34	1.07	1.48	7.11	15.75	2.21	139.21	34.18B	3.12B	88.92	35.74	2.38B	64.74	5.05	.63	121.94	16.93	1.44	95.36	220.7C
10	5.57B	.34	1.04	1.44	7.18	15.94	2.20	137.19	34.56B	3.03B	85.80	35.46	2.27AB	62.28	5.04	.63	122.55	17.01	1.47	83.46	209.4B
15	5.16A	.32	1.01	1.39	7.14	15.64	2.15	136.26	32.63A	2.83A	85.62	34.06	2.20A	63.00	5.10	.61	116.79	16.58	1.35	78.44	188.5A
S.E.	.13	.01	.03	.03	.14	.20	.05	2.72	.46	.06	1.56	.46	.05	1.07	0.10	.02	3.17	.26	.06	8.18	4.00

[1]Means followed by different non-capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .05$).

[2]Means followed by different capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .01$).

Table 9. Effect of week, fibre type and fibre level on means of adjusted (ratio method) G.I. tract measurements in cockerels fed non-pelleted diets.

	Liver weight gm/kg	Gall blad. weight gm/kg	Pancreas weight gm/kg	Provent. weight gm/kg	Ventric. weight gm/kg	Duodenum			Jejunum			Ileum			Colon			Caecum			Body weight gm.
						Length cm/kg	Weight gm/kg	Density mg/cm/kg	Length cm/kg	Weight gm/kg	Density mg/cm/kg	Length cm/kg	Weight gm/kg	Density mg/cm/kg	Length cm/kg	Weight gm/kg	Density mg/cm/kg	Length cm/kg	Weight gm/kg	Density mg/cm/kg	
Week																					
2	28.31B[1]	1.68b[2]	5.35C	8.35C	40.59C	129.07C	15.45C	1082.5C	273.30C	18.64C	616.1C	272.56C	12.88C	426.9C	40.11C	3.47C	782.0C	122.68C	7.31B	66.2C	112.7A
3	27.99B	1.51ab	5.13B	7.19B	34.62B	85.36B	11.40B	729.1B	183.34B	15.30B	456.3B	188.74B	11.57B	334.6B	27.42B	3.00B	600.6B	89.69B	7.28B	39.7B	186.1B
4	25.63A	1.44a	4.47A	6.17A	30.73A	52.45A	8.32A	477.5A	113.84A	12.23A	324.0A	122.38A	10.05A	247.1A	17.27A	2.78A	485.4A	61.66A	6.26A	19.1A	338.4C
Fibre type																					
Cellulose	27.13	1.59	5.12	7.17	35.02	88.47	11.68	768.8	187.92	15.27	469.2	194.69	11.65	341.4	28.37	3.12	632.5	90.07	6.70	40.3	211.3
Aspen	27.49	1.50	5.19	7.30	35.60	89.46	11.77	757.3	192.39	15.251	461.7	194.43	11.36	330.9	28.1	3.04	612.9	92.61	7.20	43.0	213.4
% Fibre level																					
0	26.59	1.47	4.70A	6.85A	31.18A	82.12A	11.06A	714.8A	179.26A	14.54A	429.7A	182.25A	11.10A	318.7A	26.45A	2.81A	558.3A	84.80A	6.53	36.2A	230.9C
5	27.64	1.53	5.08B	7.09AB	33.54B	84.48A	11.23A	733.4A	181.11AB	15.18AB	458.1B	187.56A	11.22A	323.7A	26.59A	2.97A	605.6AB	86.39A	6.66	37.6A	220.7C
10	26.97	1.62	5.22B	7.25B	36.77C	91.24B	11.96AB	773.5A	196.25BC	15.54B	462.0B	198.54B	11.43A	333.0A	28.43A	3.15A	643.1BC	93.83B	7.30	44.4B	209.4B
15	28.05	1.56	5.59C	7.75C	39.76D	98.00C	12.65B	830.4B	204.24C	16.30C	512.0C	209.90C	12.25B	369.5B	31.60B	3.39B	683.7C	100.35C	7.31	48.5B	188.5A
S.E.	.44	.08	.13	.11	.70	1.97	.27	18.1	4.11	.26	7.8	3.62	.19	5.7	.72	.08	17.9	1.78	.26	1.8	4.0

[1]Means followed by different non-capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .05$).

[2]Means followed by different capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .01$).

Table 10. Means, adjusted by covariance analysis, of gastrointestinal measurements where significant level effects occurred (without significant interaction) in cockerels fed non-pelleted diets.

Fibre level	Ventric. weight gm	Colon weight gm	Jejunum density gm/cm	Ileum density gm/cm	Colon density gm/cm
0	6.33A[1]	.58A	84.07a[2]	63.18a	112.71a
5	6.90B	.61AB	88.47ab	63.49a	119.22ab
10	7.25B	.64AB	86.31ab	62.72a	123.52b
15	7.72C	.66B	89.79b	66.61b	124.63b
S.E.	.13	.02	1.36	.92	3.03

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 11. Effect of fibre type and fibre level on growth and feed intake of cockerels fed pelleted diets.

		Weight gain (gm/chick/21 days)	Feed intake (gm/chick/21 days)	Feed/gain ratios (gm feed/gm gain)	
				As fed	Basal
Fibre type	Alpha Cellulose	252.4	597.0	2.40	2.16
	Aspen	251.9	596.3	2.40	2.15
	S.E.	5.34	10.84	.02	.02
Fibre level (%)	0	276.3B[1]	583.9	2.11A	2.11
	5	265.8B	599.3	2.26B	2.17
	10	265.2B	625.2	2.36B	2.13
	15	225.6A	579.6	2.58C	2.19
	S.E.	7.56	15.33	.03	.02

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

270.0 grams (Table 6).

Significant reduction ($P \leq .01$) in body weight occurred only at the highest level (15%) of included fibre. The birds tended to consume more feed up to the 10% level, although this trend was not evident with the lowest density ration (15% fibre). No differences in basal feed utilization were notable between fibre levels and no differences in performance with the two fibre types were detected.

2. Nutrient retention

Pelleting the rations resulted in a general improvement in nutrient retention (Table 12) as indicated by the dry matter retained in the control groups: 75.6% in the pelleted group versus 64.5% in the mash group (Table 7). A consistent decrease ($P \leq .01$) in dry matter, calcium and ether extract retention with increasing fibre in the diet was observed. No differences occurred in phosphorus, crude fibre or nitrogen retention.

3. Gastrointestinal tract measurements

Differences occurring in unadjusted organ weights between levels, illustrated in Table 13, were limited to liver weight ($P \leq .01$), pancreas weight ($P \leq .05$) and crop weight ($P \leq .05$). Ileum weight and density ($P \leq .01$) were greater for the cellulose group than the wood aspen group. Duodenum density, however, was lower ($P \leq .05$) for the former group.

Comparison of adjusted organ weights between levels (Table 14) again resulted in significant differences in most parameters. No differences occurred with liver, gall bladder, ventriculus and caecum

Table 12. Effect of fibre type and fibre level on nutrient retention (%) of cockerels fed pelleted diets.

Source		Dry matter	Nitrogen	Ether extract	Crude fibre	Calcium	Phosphorus
Fibre type	Alpha Cellulose	67.11A[1]	54.66	86.79b[2]	-3.51	35.11A	30.52
	Aspen	69.13B	53.09	85.52a	-10.75	40.03B	29.43
	S.E.	.16	1.29	.34	1.64	.94	1.39
Fibre level	0	75.56D	51.60	88.85B	-4.51	41.06B	29.33
	5	70.57C	53.08	87.20B	-4.56	38.71B	32.02
	10	65.09B	56.06	84.45A	-0.83	35.24A	31.30
	15	62.25A	54.78	84.13A	+2.87	35.27A	27.15
	S.E.	.23	1.83	.48	2.32	.94	1.96

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 13. Effect of week, fibre type and fibre level on means of unadjusted G.I. tract measurements in cockerels fed pelleted diets.

	Liver weight gm	Gall blad. weight gm	Pancreas weight gm	Provent. weight gm	Ventric. weight gm	Crop weight gm	Duodenum Length cm	Duodenum Weight gm	Duodenum Density mg/cm	Jejunum Length cm	Jejunum Weight gm	Jejunum Density mg/cm	Ileum Length cm	Ileum Weight gm	Ileum Density mg/cm	Colon Length cm	Colon Weight gm	Colon Density mg/cm	Caecum Length cm	Caecum Weight gm	Caecum Density mg/cm	Body Weight gm
Week																						
2	5.19A[1]	.05A	1.00A	1.38A	5.86A	0.80A	14.42A	1.95A	135.5A	31.71A	2.79A	88.0A	31.33A	1.97A	63.4A	4.85	.55A	113.0A	16.02A	1.28A	80.1A	196.7A
3	7.32B	.09B	1.23B	1.79B	7.58B	1.26B	15.48B	2.26B	146.2B	34.58B	3.43B	99.5B	36.42B	2.64B	72.7B	4.98	.74B	149.8B	18.43B	2.01B	108.1B	295.9B
Fibre type																						
Cellulose	6.39b[2]	.07	1.15	1.61	6.75	1.06	15.21	2.10	137.3a	32.99	3.09	93.2	33.67	2.39B	70.9B	4.85	.64	132.9	17.14	1.60	92.3	249.1
Aspen	6.11a	.07	1.08	1.56	6.70	1.01	14.69	2.12	144.5b	33.30	3.13	94.3	34.08	2.22A	65.2A	4.98	.64	129.9	17.31	1.69	95.9	243.4
Fibre level																						
0	6.51B	.06	1.04a	1.58	6.58	0.99a	15.03	2.10	139.4	33.35	3.05	90.8	34.07	2.30	68.0	4.93	.63	125.9	17.03	1.67	96.6	258.0A
5	6.41B	.07	1.15ab	1.64	6.74	1.01a	14.99	2.14	142.0	33.22	3.11	93.5	33.98	2.27	66.4	4.90	.63	130.7	17.39	1.64	93.1	258.0A
10	6.29B	.07	1.19b	1.60	6.86	0.98a	15.07	2.07	136.6	33.37	3.16	94.8	34.03	2.29	67.4	4.85	.64	132.8	17.05	1.61	93.2	244.3B
15	5.80A	.07	1.08ab	1.52	6.71	1.16b	14.70	2.13	145.4	32.64	3.12	95.9	33.42	2.36	70.3	4.99	.68	136.3	17.43	1.67	93.5	224.7C
S.E.	.12	.01	.04	.05	.18	.05	.27	.06	3.5	.61	.09	2.5	.64	.07	2.1	.13	.03	4.8	.27	.10	8.2	4.8

[1] Means followed by different non-capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .05$).

[2] Means followed by different capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .01$).

Table 14. Effect of week, fibre type and fibre level on means of adjusted (ratio method) G.I. tract measurements in cockerels fed pelleted diets.

	Liver weight gm/kg	Gall blad. weight gm/kg	Pancreas weight gm/kg	Provent. weight gm/kg	Ventric. weight gm/kg	Crop weight gm/kg	Duodenum			Jejunum			Ileum			Colon			Caecum		
							Length cm/kg	Weight gm/kg	Density gm/cm/kg	Length cm/kg	Weight gm/kg	Density gm/cm/kg	Length cm	Weight gm	Density gm/cm/kg	Length cm	Weight gm	Density gm/cm/kg	Length cm	Weight gm	Density gm/cm/kg
Week																					
2	26.4B[1]	.26	5.1B	7.0	29.9	4.1	73.8B	10.0B	.69B	162.4B	14.2B	.45B	160.4B	10.1B	.32B	24.7B	2.8b	.58B	81.9B	6.5	.41b
3	24.8A	.29	4.2A	6.1	25.8	4.4	52.9A	7.7A	.50A	118.2A	11.6A	.34A	124.6A	9.0A	.25A	17.1A	2.5a	.51A	62.9A	6.8	.37a
Fibre type																					
Cellulose	25.8	.28	4.8	6.6	27.8	4.3	64.0	8.7	.62B	138.5	12.6A	.39	140.4	9.8b	.30b	20.5	2.6	.54	71.5	6.4	.38
Aspen	25.4	.27	4.5	6.5	28.0	4.2	62.7	9.0	.57A	142.1	13.2B	.40	144.6	9.3a	.28a	21.4	2.7	.55	73.3	6.9	.40
Fibre level																					
0	25.5	.23	4.2A	6.3A	26.1	3.9A	62.0A	8.6A	.57A	136.8A	12.2A	.37A	138.2A	9.1A	.28A	20.4A	2.5A	.50A	69.0A	6.5	.38
5	25.0	.27	4.5AB	6.4AB	26.5	3.9A	59.9A	8.4A	.57A	132.2A	12.2A	.37A	134.9A	8.9A	.26A	19.7A	2.5A	.51A	69.3A	6.3	.36
10	25.9	.28	5.0B	6.6AB	28.5	4.0A	63.8AB	8.6A	.58A	142.3AB	13.2B	.40A	144.2AB	9.5A	.28A	20.7A	2.7A	.55A	72.0A	6.6	.39
15	26.0	.31	4.9B	6.9B	30.3	5.1B	67.6B	9.7B	.67B	149.8B	14.1C	.44C	152.7B	10.5B	.32B	22.9B	3.0B	.61B	79.4B	7.3	.42
S.E.	.30	.03	.15	.15	.62	.21	1.43	.23	.01	3.21	.28	.01	3.52	.20	.01	2.16	.01	.02	1.27	.31	.02

[1]Means followed by different non-capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .05$).

[2]Means followed by different capitalized letters within columns for week, fibre type and % fibre level are significantly different ($P \leq .01$).

weights. Caecum density was also not affected by fibre level. Consistent with the previous study, the greater organ weights were associated with the smaller bird size or the highest dietary fibre level. Differences between fibre types occurred with duodenum density, where the cellulose group was thicker ($P \leq .01$) than the wood aspen birds; and with ileum weight and density ($P \leq .05$) which were also larger with those birds fed cellulose diets.

The results using the regression procedure and covariance analysis revealed significant increases ($P \leq .01$) in ventriculus, crop, ileum and colon weights particularly at the highest level of fibre dilution (Table 15). Increases at the higher levels of included fibre were also evident for jejunum weight and density ($P \leq .05$), ileum density ($P \leq .05$), colon density ($P \leq .01$) and caecum length ($P \leq .01$).

C. Effect of age and body weight on gastrointestinal development

Figures 2 and 3 graphically illustrate the effect of body weight and age on the development of various organs of the gastrointestinal tract. The most dramatic effect, apparent in all graphs, is the increase in variability of organ weight or length with increased age or body weight.

Liver and pancreas weight (Figure 2) increase rapidly until about 5 weeks; when a second, less rapid growth phase occurs. The proventriculus and ventriculus (Figure 2) development is more consistently linear up to the 14 week termination of the experiment.

The most striking observation with intestinal development (Figure 3) is the difference in growth rate between weight and length. Due to

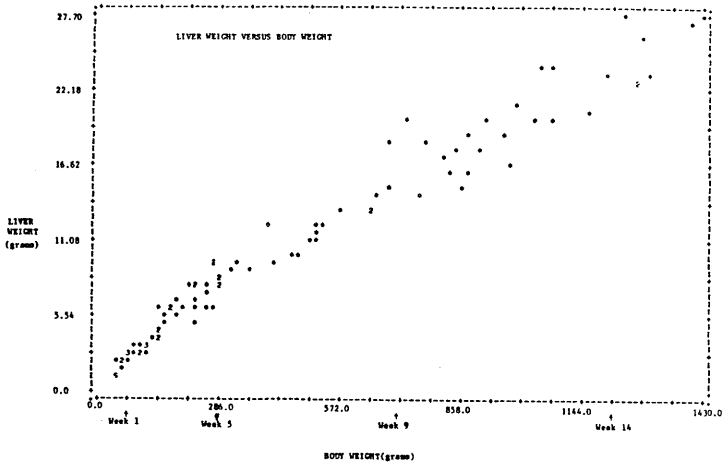
Table 15. Means, adjusted by covariance analysis, of gastrointestinal measurements where significant level effects occurred (without significant interaction) in cockerels fed pelleted diets.

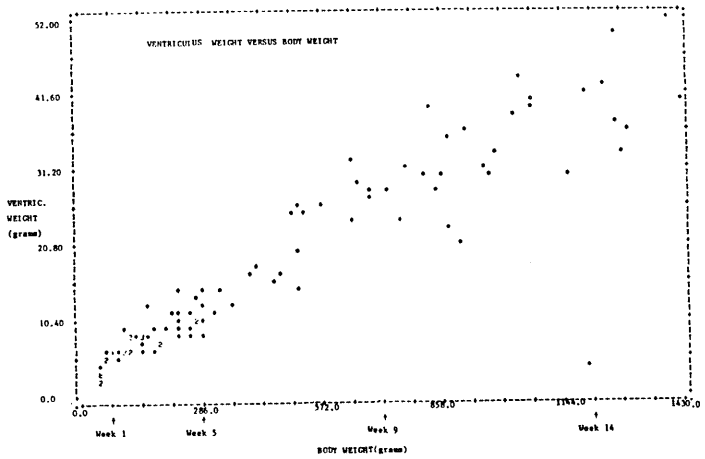
	Body weight gm	Ventric. weight gm	Crop weight gm	Jejunum weight gm	Jejunum density mg/cm	Ileum weight gm	Ileum density mg/cm	Colon weight gm	Colon density mg/cm	Caecum length cm
Fibre level										
0	258.0A[1]	6.37A	.94A	2.96a[2]	89.07a	2.22A	66.68a	.60A	121.72A	16.72A
5	258.0A	6.54AB	.96A	3.02a	91.74ab	2.18A	65.13a	.60A	126.48A	17.09A
10	244.3B	6.89BC	.98A	3.18ab	95.07ab	2.30B	67.59a	.64A	133.45AB	17.09A
15	224.7C	7.09C	1.24B	3.29b	99.00b	2.50C	72.68b	.71B	143.99B	17.97B
S.E.	4.8	.15	.05	.07	2.21	.07	1.93	.02	4.60	.24

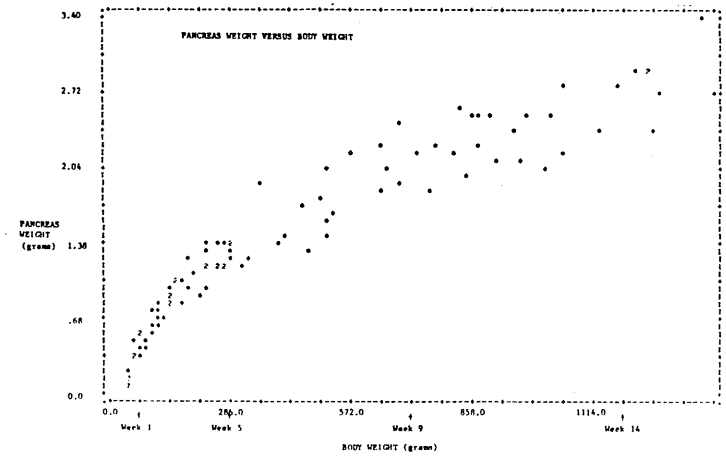
[1]Means followed by different capitalized letters within columns are significantly different $P \leq .01$.

[2]Means followed by different non-capitalized letters within columns are significantly different $P \leq .05$.

Figure 2 . Effect of age and body weight on liver,pancreas,proventriculus and ventriculus weight in young cockerels.







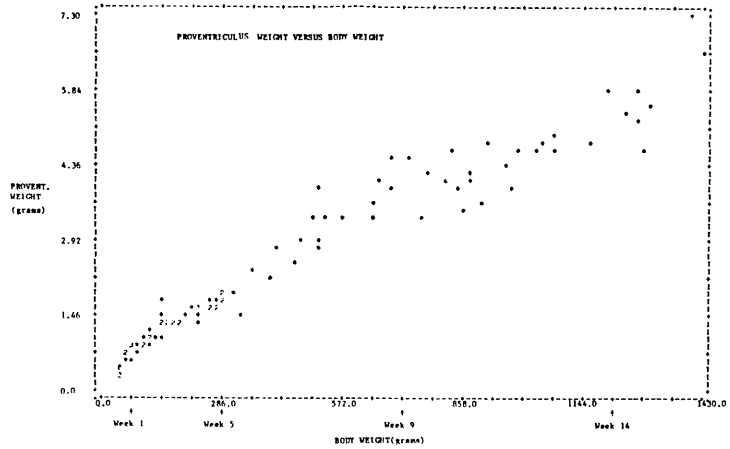
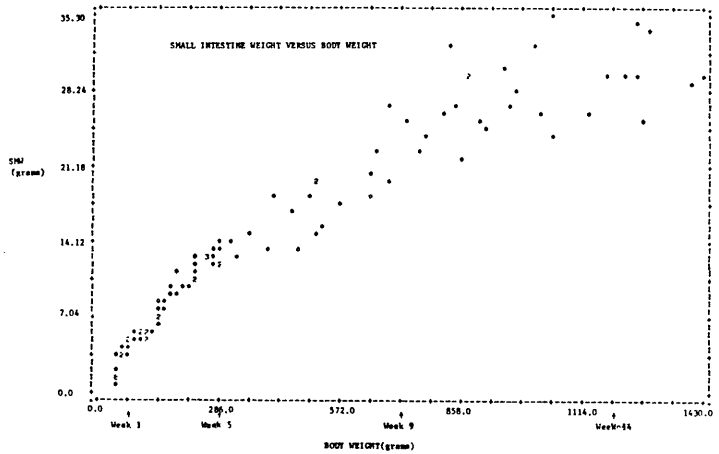
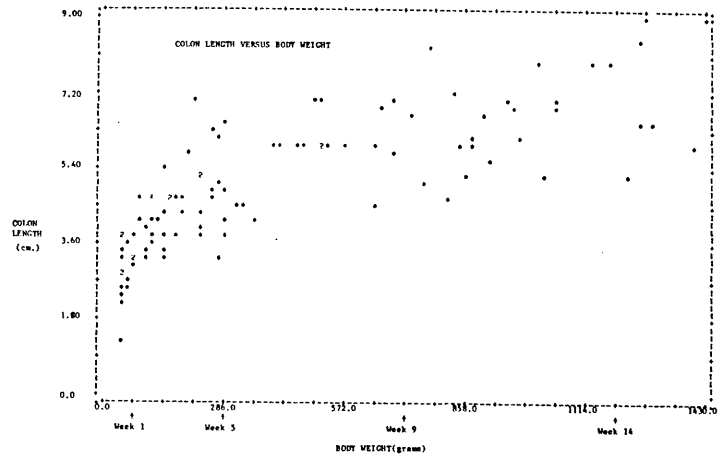
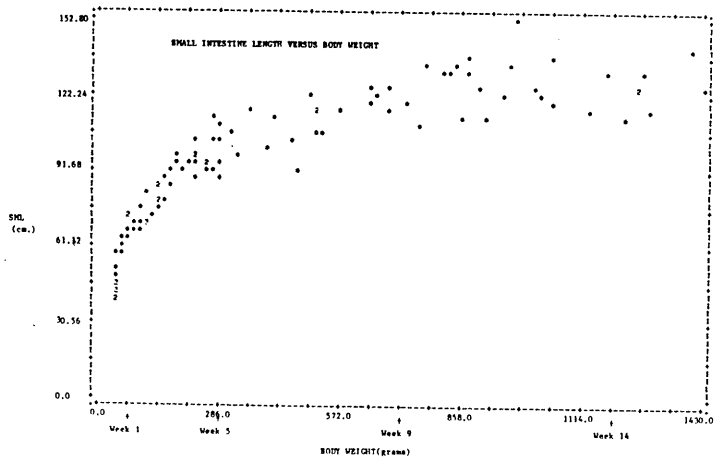
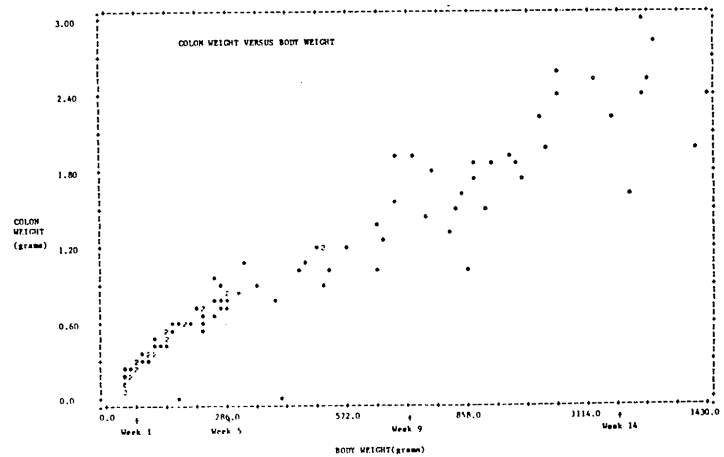


Figure 3 . Effect of age and body weight on small intestine and colon length and weight in young cockerels.









an initial rapid increase, the small intestine has reached 80-95% of its complete length within 5-7 weeks. The weight, however, increases less rapidly but at a constant rate at least until 14 weeks. A similar pattern occurred with the colon (Figure 3), although large variability in length measurements was apparent.

II. BROILER BREEDER STUDIES

A. Study 1 - Major growth and production trial

1. Grower phase

Growth and feed intake

Table 16 summarizes the results of the 20 week grower period. The significant ($P \leq .01$) reduction in weight gain (18-19%) with the fibre and restricted wheat diets from the full fed wheat diet was slightly less than the 22% reduction with the restricted rye group. Total feed intake for the restricted groups followed a similar pattern when the fibre diet is considered in terms of basal intake ($17.01x \simeq .70 = 11.91$ kg). Thus the 20% weight reduction in all restricted groups could be related to a 20% decrease in basal feed intake when compared to the full fed wheat diet.

At three weeks the flock was stricken with a disease outbreak. In spite of a determined effort to discover the cause, no definitive diagnosis has been made. Feed contamination was not a factor since the cockerel study (number III) used the same diets and these birds were disease free. The full fed fibre group was least affected with only a 6.2% mortality rate. Mortality was negligible during the rest of the

Table 16. Growth and feed intake of broiler breeder pullets during growing phase (to 20 weeks).

Diet	Weight gain at 20 weeks (kg/bird)	Total feed intake (kg/bird)	Feed efficiency (kg feed/kg gain)	Disease mortality[2] (%)
Full fed wheat	4.03C[1](100.0)[5]	15.76B (100.0)	3.92A	----[3]
Full fed fibre	3.31B (82.1)	17.01C (107.9)	5.14B (3.60)[4]	6.2
Restricted wheat	3.26B (80.9)	12.43A (78.9)	3.82A	21.8
Restricted rye	3.13A (77.7)	12.47A (79.1)	3.99A	12.9
S.E.	.07	.25	.07	

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2](Disease Mortality[2]) Unidentified disease outbreak at 3 weeks. No appreciable mortality occurred during the remainder of grower phase.

[3]----[3] Full fed wheat diet introduced after disease outbreak.

[4]Computed on a basal intake basis.

[5]Percent of full fed wheat (parenthesis).

grower phase.

Body conformation

Although no significant differences were noted in circumference and keel length (Table 17), variable results occurred with body length and tibia measurements depending on the method of statistical analysis. The smaller, rye fed birds had shorter tibias ($P \leq .05$) on an absolute basis, but not when adjusted for body weight using the "Ratio Method". Conversely, body length was not different with different treatments unless expressed per unit body weight. The smaller, rye fed birds were significantly ($P \leq .05$) longer than the full fed control and restricted wheat, although the full fed fibre birds were similar in length.

Gastrointestinal tract measurements

Insufficient replication prevented the useful application of the regression model for comparison of organ development under the different grower diets and dietary regimes. Tables 18 to 28 summarize the results over the three sampling periods using two of the three methods of data analysis. Unadjusted weights and lengths are compared with those adjusted using the Ratio Method. Only those differences consistent over the three sampling periods will be considered because of the nature of the sampling technique and the increase in variability with age. Mean body weights of sampled birds are shown in Table 18.

Liver weight (Table 19) for the fibre fed group was consistently smaller ($P \leq .05$) on an unadjusted basis and this trend was maintained when analyzed using the "Ratio Method". A correspondingly smaller

Table 17. Comparison of unadjusted and adjusted (ratio method) means of body conformation of broiler breeder pullets at 22 weeks fed the different grower diets or regimes.

A. Unadjusted

Diet	Weight (kg)	Circumference (cm)	Keel (cm)	Body length (cm)	Tibia (cm)
Full fed wheat	4.3A[1]	45.2	14.8	25.4	16.4b[2]
Full fed fibre	4.0B	44.8	15.0	26.0	16.5b
Restricted wheat	4.0B	43.6	15.5	25.2	16.4b
Restricted rye	3.6C	42.8	14.4	24.5	15.4a
S.E.	0.14	1.12	0.28	0.60	0.32

B. Adjusted

Full fed wheat		10.5	3.5	5.9a	4.0
Full fed fibre		11.2	3.9	6.5bc	4.2
Restricted wheat		10.9	3.8	6.3ab	4.1
Restricted rye		11.9	4.0	6.8c	4.3
S.E.		3.7	.14	.22	.13

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 18. Comparison of means of body weights (kg) between treatments over the three sampling periods.

	Body weight (kg)		
Week	6	15	20
Treatment			
Full fed wheat	-	3.58C	4.02C
Full fed fibre	1.04B[1]	2.59A	2.95A
Restricted wheat	1.00B	2.69AB	3.60BC
Restricted rye	.86A	3.00B	3.26AB
S.E.	.02	.08	.11

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

Table 19. Comparison of unadjusted and adjusted (ratio method) means of liver weight between treatments over the three sampling periods

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	48.4b	64.7c	-	13.5AB[1]	15.8
Full fed fibre	21.4a[2]	32.6a	32.6a	20.5A	12.5A	11.1
Restricted wheat	22.4a	41.3ab	56.3b	22.5A	15.3B	15.6
Restricted rye	26.5b	47.1b	51.0b	30.7B	15.7B	15.6
S.E.	.72	1.56	3.81	.83	.40	.74

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 20. Comparison of unadjusted and adjusted (ratio method) means of pancreas weight between treatments over the three sampling periods.

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	5.4b[2]	5.4	-	1.5	1.3A
Full fed fibre	2.5	4.2a	4.7	2.4A[1]	1.6	1.6AB
Restricted wheat	2.6	4.0a	4.9	2.6A	1.5	1.4A
Restricted rye	2.7	4.8ab	5.5	3.1B	1.6	1.7B
S.E.	.06	.17	.19	.08	.04	.05

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 21. Comparison of unadjusted and adjusted (ratio method) means of proventriculus weight between treatments over the three sampling periods.

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	8.1ab[2]	6.7	-	2.3A	1.7A
Full fed fibre	3.8	6.8a	6.0	3.7A[1]	2.6AB	2.0AB
Restricted wheat	4.0	8.4a	6.7	4.0A	3.1B	1.9AB
Restricted rye	4.0	8.9b	7.0	4.6B	3.0B	2.1B
S.E.	.11	.22	.23	.11	.08	.06

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 22. Comparison of unadjusted and adjusted (ratio method) means of ventriculus weight between treatments over the three sampling periods.

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	53.5a	45.3a	-	15.0A	11.5A
Full fed fibre	29.1b[2]	74.6b	62.7b	28.2C[1]	28.8B	21.2B
Restricted wheat	21.8a	70.2ab	47.6a	21.9A	26.2B	13.3A
Restricted rye	21.3a	71.9ab	52.0a	24.7B	24.1B	15.7AB
S.E.	.73	2.89	3.29	.58	1.30	1.12

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 23. Comparison of unadjusted and adjusted (ratio method) means of weight of abdominal fat between treatments at 20 weeks.

	Unadjusted (gm)	Adjusted (gm/kg body wt.)
Week	20	20
Treatment		
Full fed wheat	207.0c[2]	51.8b
Full fed fibre	91.7a	30.7a
Restricted wheat	193.5c	53.7b
Restricted rye	131.5b	35.0a
S.E.	13.44	8.10

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 24. Comparison of unadjusted and adjusted (ratio method) means of duodenum length, weight and density between treatments over the three sampling periods.

A. Length

	Unadjusted (cm)			Adjusted (cm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	33.0	30.6	-	9.3A	7.7
Full fed fibre	25.2	30.0	26.0	24.6A[1]	11.6B	8.9
Restricted wheat	27.1	32.6	29.0	27.5A	12.1B	8.0
Restricted rye	29.3	32.9	28.8	34.3B	10.9AB	8.8
S.E.	.49	.79	.70	.85	.32	.22

B. Weight

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	12.1b	10.3	-	3.4A	2.6
Full fed fibre	5.7a[2]	9.0a	8.4	5.6A	3.5A	2.9
Restricted wheat	7.1b	11.9b	9.9	7.1B	4.4B	2.8
Restricted rye	7.9b	12.7b	11.0	9.2C	4.2B	3.4
S.E.	.22	.40	.41	.28	.12	.12

C. Density

	Unadjusted (gm/cm)		
Week	6	15	20
Treatment			
Full fed wheat	-	.37AB	.34
Full fed fibre	.23a	.30A	.32
Restricted wheat	.26ab	.36AB	.35
Restricted rye	.27b	.40B	.38
S.E.	.01	.01	.01

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 25. Comparison of unadjusted and adjusted (ratio method) means of jejunum length, weight and density between treatments over the three sampling periods.

A. Length

	Unadjusted (cm)			Adjusted (cm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	74.8	61.5	-	21.1A	15.6A
Full fed fibre	60.7a[2]	70.5	66.3	59.4A[1]	27.2B	22.6B
Restricted wheat	64.7a	74.9	73.9	65.4A	27.8B	20.5B
Restricted rye	71.7b	76.6	71.7	83.9B	25.5B	22.0B
S.E.	1.26	1.29	2.21	2.22	.61	.80

B. Weight

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	24.7	18.4	-	6.9	4.6a
Full fed fibre	11.4a	19.2	16.2	11.0A	7.4	5.5ab
Restricted wheat	12.5a	29.3	19.0	12.5B	10.7	5.3ab
Restricted rye	14.1b	26.5	21.4	16.4C	8.8	6.5b
S.E.	.31	1.81	.91	.40	.58	.26

C. Density

	Unadjusted (gm/cm)		
Week	6	15	20
Treatment			
Full fed wheat	-	.33	.31
Full fed fibre	.19	.27	.25
Restricted wheat	.19	.39	.26
Restricted rye	.20	.35	.29
S.E.	.01	.02	.01

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 26 Comparison of unadjusted and adjusted (ratio method) means of ileum length, weight and density between treatments over the three sampling periods.

A. Length

	Unadjusted (cm)			Adjusted (cm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	70.4	64.2	-	19.8A	16.1A
Full fed fibre	61.5a[2]	69.9	60.9	60.0A[1]	27.0B	20.8B
Restricted wheat	63.8ab	72.9	67.5	64.7A	27.1B	18.7AB
Restricted rye	69.4b	76.2	68.7	81.3B	25.4B	21.1B
S.E.	1.12	1.10	1.87	2.03	.63	.66

B. Weight

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	17.8	13.4	-	4.9A	3.3A
Full fed fibre	8.7	16.1	13.0	8.4A	6.2AB	4.5B
Restricted wheat	9.1	16.8	13.6	9.2A	6.3B	3.8AB
Restricted rye	9.9	19.2	15.4	1.5B	6.5B	4.7B
S.E.	.22	.62	.55	.27	.20	.17

C. Density

	Unadjusted (gm/cm)		
Week	6	15	20
Treatment			
Full fed wheat	-	.25	.21
Full fed fibre	.14	.23	.22
Restricted wheat	.15	.23	.21
Restricted rye	.14	.26	.22
S.E.	.01	.01	.01

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 27. Comparison of unadjusted and adjusted (ratio method) means of colon length, weight and density between treatments over the three sampling periods.

A. Length

	Unadjusted (cm)			Adjusted (cm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	10.3	9.9	-	2.9A[1]	2.5
Full fed fibre	8.6b[2]	10.6	7.8	8.4	4.0B	2.7
Restricted wheat	7.2a	10.7	9.1	7.3	4.0B	2.5
Restricted rye	7.1a	9.2	7.8	8.4	3.1A	2.4
S.E.	.21	.29	.33	.26	.14	.10

B. Weight

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	4.5	3.8	-	1.3A	.96
Full fed fibre	2.4b	4.9	4.2	2.3B	1.9B	1.5
Restricted wheat	1.8a	4.2	3.6	1.8A	1.6AB	1.0
Restricted rye	1.8a	4.3	3.4	2.1AB	1.4A	1.1
S.E.	.08	.16	.19	.06	.07	.07

C. Density

	Unadjusted (gm/cm)		
Week	6	15	20
Treatment			
Full fed wheat	-	.44	.39
Full fed fibre	.29	.46	.56
Restricted wheat	.26	.39	.39
Restricted rye	.25	.47	.45
S.E.	.01	.01	.03

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 28. Comparison of unadjusted and adjusted (ratio method) means of caecum length, weight and density between treatments over the three sampling periods.

A. Length

	Unadjusted (cm)			Adjusted (cm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	42.0	43.8	-	11.8A	11.0a
Full fed fibre	32.5	40.3	38.5	31.8A[1]	15.6B	13.1b
Restricted wheat	31.1	41.5	39.7	31.5A	15.4B	11.1a
Restricted rye	33.8	42.8	42.9	39.6B	14.3B	13.2b
S.E.	.48	.69	.91	.93	.34	.35

B. Weight

	Unadjusted (gm)			Adjusted (gm/kg body wt.)		
Week	6	15	20	6	15	20
Treatment						
Full fed wheat	-	10.8b	9.9b	-	3.0AB	2.5A
Full fed fibre	3.6a[2]	8.2a	7.1a	3.5A	2.8A	2.4A
Restricted wheat	4.7b	10.4b	7.7a	4.7B	3.9BC	2.1A
Restricted rye	4.9b	12.3c	11.6c	5.7C	4.0C	3.6B
S.E.	.13	.36	.47	.17	.16	.15

C. Density

	Unadjusted (gm/cm)		
Week	6	15	20
Treatment			
Full fed wheat	-	.26B	.22AB
Full fed fibre	.11A	.18A	.18A
Restricted wheat	.15B	.25B	.20A
Restricted rye	.15B	.29B	.27B
S.E.	.01	.01	.01

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

($P \leq .05$) abdominal fat pad (Table 23) was observed at 20 weeks. Increased ventriculus weight (Table 22) was a characteristic response for both the unadjusted ($P \leq .05$) and adjusted ($P \leq .01$) methods of analysis. The only noticeable effect of the fibre diet on intestinal development was seen with the colon (Table 29) where a trend towards increased weight and density was apparent.

Duodenum density (Table 24), ileum length and weight (Table 26) and caecum (Table 28) length, weight ($P \leq .05$) and density ($P \leq .01$) were consistently larger for the rye fed birds when compared to the other three treatments. Size of the abdominal fat pad (Table 23) was significantly ($P \leq .01$) smaller than in the wheat fed birds; but slightly greater than the fibre fed birds.

Few consistent responses could be detected between the two wheat fed groups, indicating that the skip-a-day system had a minimal influence on organ development.

2. Layer phase

A summary of the effects of the grower regimes on production during the 5 month layer period is shown in Table 29. A significant ($P \leq .05$) delay in sexual maturity for the restricted groups versus the full fed groups is indicated by the seven day difference in days to first egg. Increased production ($P \leq .05$) was also evident with the skip-a-day system. Reduced egg weight ($P \leq .05$) with the fibre fed groups when compared to the wheat-based diets was coincident with the poorest hen-day (%) production. The low mortality observed during the grower phase (Table 16) with the fibre diluted diet continued into the laying phase.

Table 29. Effect of grower diet of broiler breeder pullets on subsequent layer performance

Grower Diet	Days to first egg		Egg production[2] (% hen-day)		Egg weight[2] (gms)	Mortality 20-40 weeks
Full fed wheat	145.2)		62.0)		59.3b	7.5
	)	145.9A[1]		) 61.4a		
Full fed fibre	146.6)		60.8)		57.5a	1.2
Restricted wheat	152.2)		67.1)		59.1b	5.9
	)	153.0B		) 69.3b		
Restricted rye	153.8)		71.4)		58.2ab	5.9
S.E.	3.1	2.1	3.4	2.3	.50	

[1]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

[2]Means of 4 months following 50% hen-day production.

These birds were also well feathered and quiet in nature.

Figure 4 illustrates the change in weekly % hen-day production for four treatment groups. The rye grower and layer diets resulted in the best overall performance and the highest peak production.

Table 30 presents the data from the hatchability study based upon the three day collection period. The few viable roosters resulted in poor fertility and large between pen variability and this did not permit a meaningful comparison between dietary regimes. No drastic effects, which might be expected with the fibre or rye fed birds, were observed.

B. Study 2 - The effect of rearing regimes on the early nutrition and physiology of the broiler chick

Growth and feed intake

Introduction of the grower diets, the eight hour feeding programme and, most dramatically, the skip-a-day system at one week of age had a profound effect on growth. The birds on the restricted feeding regime grew very slowly (Table 31), and even those on the full fed wheat diets performed poorly. Adjustment to the 30% fibre dilution was rapid and these birds best adapted to the environmental constraints, as evidenced by their relatively rapid growth, high feed intake (150% of full fed wheat diet) and low mortality. The apparent poorer feed to gain ratio ($P \leq .01$) observed with the birds on the restricted diets exceeded even those fed the fibre diets. This latter group had the best feed conversion (2.69) when considered on a basal intake basis (i.e. excluding the 30% wheat straw).

FIGURE 4 . BROILER BREEDER PULLET EGG PRODUCTION

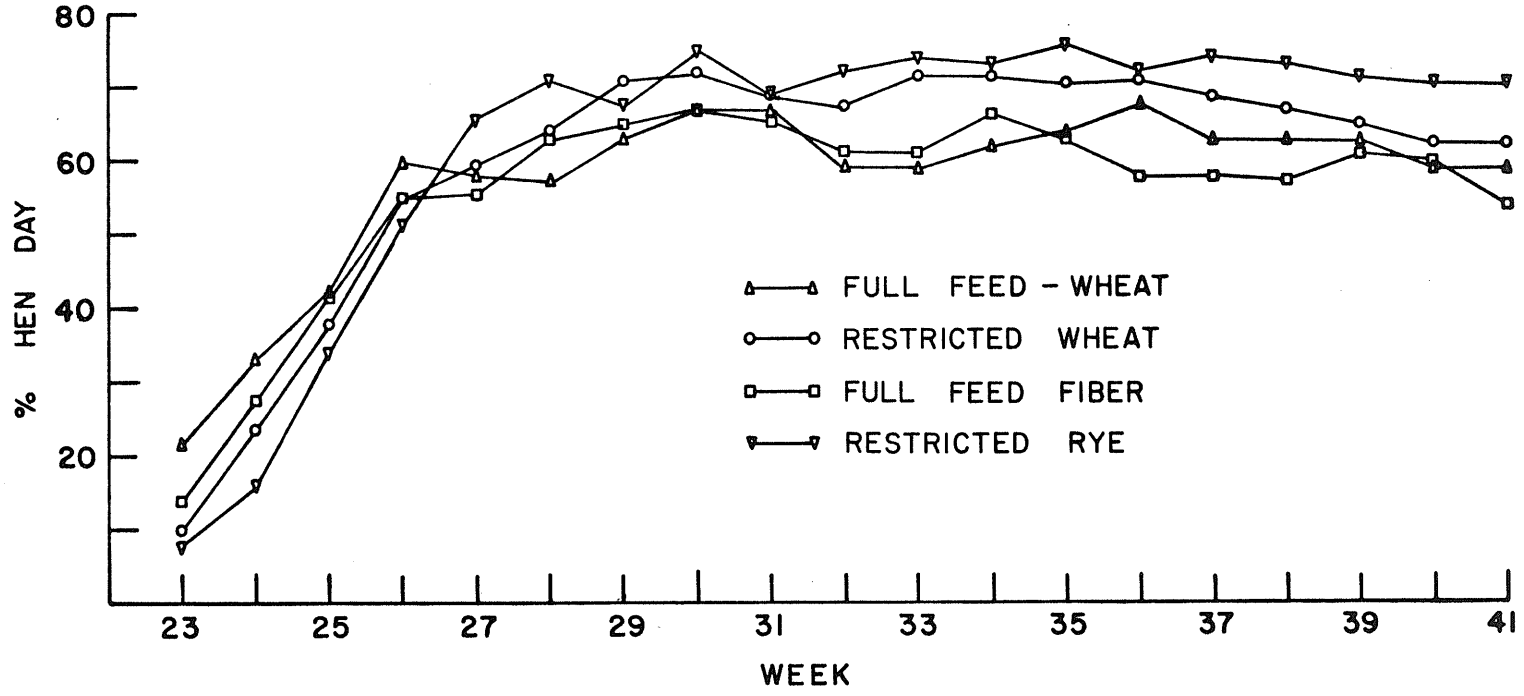


Table 30. Effect of grower diet of broiler breeder pullets on hatchability during the layer phase.

Grower Diet	No. of eggs set	Hatchability (%)	
		Eggs set	Fertile eggs[1]
Full fed wheat	111	69.8	86.6
Full fed fibre	133	56.9	90.3
Restricted wheat	122	77.3	83.5
Restricted rye	142	67.1	83.7
S.E.		7.4	3.7

[1]Low fertility due to poor condition of overfed roosters.

Table 31. Growth and feed intake of broilers fed broiler breeder grower diets to seven weeks.

Diets	Average wt. gain gm/bird	Ave. feed consumption gm/bird	Feed/gain ratios	Mortality (%)
Full fed wheat	519.7B[1]	1537.2B	2.94A	1.9
Full fed fibre	595.7C	2292.0C	3.85B(2.69)[2]	0.9
Restricted wheat	139.0A	595.7A	4.30C	1.9
Restricted rye	142.9A	616.2A	4.31C	2.8
S.E.	18.3	48.0	.21	

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Calculated on a basal intake basis.

Nutrient retention

The balance trial was characterized by large between pen variability. In spite of this, definite trends do appear and are summarized in Tables 32 and 33. The expected reduction in dry matter retention ($P \leq .01$) with the fibre diet is also reflected in the significantly lower ($P \leq .01$) nitrogen corrected metabolizable energy (MEn). In addition there was a tendency towards lower crude fat retention with both the fibre and rye fed birds, and lower protein retention with the latter group. The positive retention ($P \leq .05$) of acid detergent fibre (ADF) observed with the fibre and rye diets should also be noted.

Calcium ($P \leq .01$) and magnesium (not significantly), both divalent cations, were similar in their response to fibre feeding with a 60% drop in % retention from the full fed wheat groups. Although not significant, there appeared to be higher sodium and phosphorus retention with the restricted groups and lower potassium retention with the fibre and rye fed diets.

Rate of passage

Feed consumption for all treatment groups (Table 34) was similar after the 1½ hour exposure to the marker diets. This represented 36-38% of the total feed consumed for that day by the full fed groups and 62-64% for the restricted groups. Approximately 80% of the marker was recovered after 48 hours.

Figure 5 illustrates the pattern of cummulative marker recovery for the 14 hours after introduction of the marker diet. The full fed groups had significantly ($P \leq .01$) faster rates of marker excretion than the

Table 32. Effect of grower diets on nutrient retention

Diets	Dry matter (%)	MEn (Kcal/Kg)	Nitrogen (%)	Ether extract (%)	ADF (%)	Feed intake (during balance trial) (gm/bird/day)
Full fed wheat	71.3B	2800B[1]	48.1	83.7	-5.6a[2]	47.3B
Full fed fibre	58.0A	2285A	48.2	76.5	20.1b	62.3C
Restricted wheat	75.2B	2980B	49.0	87.5	-1.9a	28.8A
Restricted rye	71.4B	2850B	44.6	80.4	4.5ab	30.8A
S.E.	2.4	85.8	2.1	2.5	5.4	3.6

[1]Means followed by different capitalized letters within columns are signficantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

Table 33. Effect of grower diets on mineral retention

Diets	Sodium (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Phosphorus (%)
Full fed wheat	26.4	32.2	41.3B[1]	11.6	31.7
Full fed fibre	28.1	21.8	18.4A	4.5	25.9
Restricted wheat	41.0	31.4	51.2B	13.0	39.7
Restricted rye	47.4	24.1	53.8B	11.6	41.2
S.E.	6.0	7.6	5.6	4.2	3.9

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

Table 34. Feed intake and marker recovery of broilers during the rate of passage study

Diet	Marker-feed intake gm	Marker-feed intake % of total	Unmarked feed intake (gm/bird)	Total intake (gm/bird)	Total marker recovery (%) after 48 hours	Body weight gm
Full fed wheat	22.7	36.2	40.0B[1]	62.7B	79.7	736.7B
Full fed fibre	26.9	37.9	44.0B	70.9B	81.3	762.2B
Restricted wheat	25.3	63.6	14.4A	39.8A	76.1	251.1A
Restricted rye	26.3	62.5	15.8A	42.1A	77.1	247.7A
S.E.	4.1		1.3	4.6	4.5	39.3

[1]Means followed by different capitalized letters within columns are significantly different $P \leq .01$.

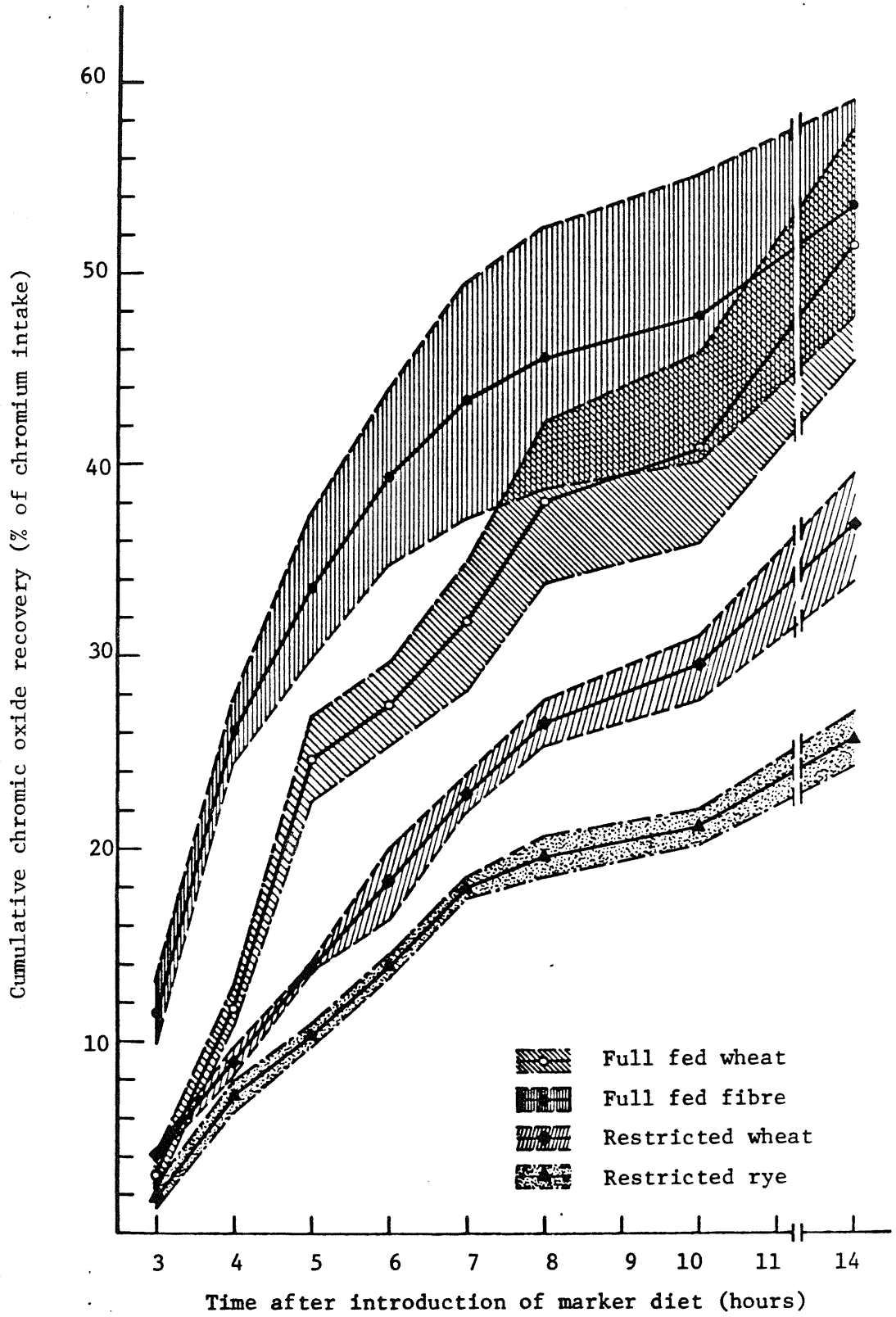


Figure 5. Pattern of cumulative chromic oxide recovery of chicks fed under the four dietary regimes.

restricted groups throughout the whole period. The higher rate of recovery for the fibre group, initially, was not continued after food removal when cumulative rates of recovery with the two diets began to merge. The rye fed birds consistently demonstrated a slower rate of recovery than those on the restricted wheat diets.

The change in percent dry matter during the first 14 hours of collection is shown in Table 35. The restricted diets tended to have a low dry matter feces during the feeding period; however this difference diminished after feed and water were removed at 1600 hours. The rye fed birds, however, had dryer feces during the latter part of the feeding period than the restricted wheat birds. The full fed fibre group showed the least fluctuation in percent dry matter over the whole sampling period. After water and food removal, differences between groups were reduced, until, at 2300 hours dry matter content was similar.

Table 35. Change in dry matter content (%) of fecal output with time during rate of passage study.

	Time of day								
Diet	12:00	13:00	14:00	15:00	16:00	17:00	19:00	23:00	Mean
Full fed wheat	23.2	28.5b[2]	30.0B[1]	32.6C	28.9B	29.4	33.8	34.5	30.1C
Full fed fibre	26.3	26.9b	23.8B	22.9B	22.7B	22.7	26.2	31.4	25.4BC
Restricted wheat	16.5	13.1a	14.9A	9.2A	13.2A	17.0	29.8	30.1	18.0A
Restricted rye	16.4	18.4ab	16.3A	19.6B	21.6B	23.9	25.6	28.4	21.3AB
S.E.	3.5	2.9	2.2	1.6	2.3	2.5	2.2	3.1	1.8

[1]Means followed by different capitalized letters within columns are significantly different ($P \leq .01$).

[2]Means followed by different non-capitalized letters within columns are significantly different ($P \leq .05$).

DISCUSSION

I. EFFECTIVENESS OF BREEDER PULLET REARING REGIMES FOR CONTROLLING GROWTH AND IMPROVING LAYER PERFORMANCE

A. General

The importance of limiting costs for broiler breeder pullet production through the use of cheaper rations or reduced labour input has been emphasized by Peters et al. (1972) and Cave (1978). The intent of the studies reported herein was to investigate the effectiveness of introducing a high fibre full feeding regime early in the growing phase of broiler breeder pullets in an attempt to simplify the complex management systems for controlling growth recommended by the breeder suppliers. Rye was included as one of the skip-a-day (restricted) diets because it is a possible replacement grain for wheat. Cost and space limitations required that a small sample of Hubbard broilers be used as a model for predicting the relative growth and performance of a broiler breeder flock fed high fibre or rye diets.

The overall performance of the flock was remarkable considering their parentage and excessive weights. This latter point, however, had a significant effect on the viability of the roosters used for the hatchability study. They were raised on the full fed wheat diet and grew to such excessive weights that their ability to perform was greatly impaired. This resulted in the very poor and highly variable fertility consistent with all treatments during the hatchability trial. The roosters might have been better conditioned if they had been raised on the restricted (skip-a-day) system.

B. Dietary Regimes

1. High fibre diets

The preliminary studies with SCWL cockerels indicated that at all levels of fiber dilution, growth depression could be directly related to a reduction in basal nutrient intake (Table 36). At the highest (15%) level of fibre dilution no compensatory increase in intake occurred, particularly in the non-pelleted ration where a 20% reduction in growth and basal intake was observed. A similar, although not as severe, response was reported by Hill and Dansky (1954) and Scott et al. (1958).

A summary (Lewis, 1978) of the recommendations of breeder suppliers indicated that a 30% reduction in nutrient intake was optimal when introduced early in the growing period. Based upon the cockerel studies, inclusion of 30% NPPF should have given at least a 30% reduction in growth and feed intake. The 20% reduction in weight at maturity for the fibre fed birds from the wheat fed birds indicated a degree of age dependent adaptation resulting in an increased capacity for feed intake and an improvement in basal feed utilization. Possibly the limited nutrients in wheat straw became more available with the older birds. All previous studies (Isaacks et al., 1960; Waldroup et al., 1966; Summers et al., 1967; Kondra et al., 1974 and Waldroup et al., 1976) introduced the diluent at much later periods, ranging from 6 to 12 weeks, and were not as effective in controlling growth. For example, Kondra et al. (1974) obtained a 13% reduction in weight with a 30% wheat straw diet introduced at 12 weeks. Waldroup et al. (1976) achieved a weight

Table 36. Effect of fiber dilution on feed intake and growth with pelleted and non-pelleted rations for young Leghorn cockerels

Fiber Dilution (%)	Pelleted		Non-pelleted	
	Relative basal intake (%)	Relative growth (%)	Relative basal intake (%)	Relative growth (%)
0	100.0	100.0	100.0	100.0
5	97.5	97.0	95.2	96.5
10	96.4	96.6	88.2	91.0
15	84.4	85.3	78.7	80.0

reduction of only 6% when using rice hulls included at 50% when compared to 20% of the ration and introduced at six weeks. This latter study rejected the use of fibre diluents based upon the inability of the diet to maintain body weights within the breeder supplier's recommended range; however, the economics of both feed and labour were not considered, no control group was included and subsequent layer performance was not evaluated.

The failure of the full fed fibre group to outperform the full fed wheat control during the laying period clearly demonstrates the inadequacy of this method. Both of the full fed systems did not delay the onset of sexual maturity when compared to the restricted regimes. Summers et al. (1967) reported no delay in sexual maturity from a full fed control group when feeding 80% wheat bran diets to pullets from 8 to 23 weeks. They did, however, report better performance with the wheat bran group (≃ 9% crude fibre) and attributed this to the 15% reduction in weight at "point of lay". A similar, favourable response during the breeding period was reported by Kondra et al. (1974) with birds fed a 30% wheat straw diet from 12-21 weeks. No data were reported on delay in sexual maturity; however the fibre birds had body weights 13% less than the full fed control group. In both of the above experiments the fibre diets were introduced relatively late in the growing period. The rapid improvement in the genetics for growth in broilers since these experiments were conducted would make the late restriction method inappropriate. This does not rule out the possibility of combining other restriction methods initially, with full fibre feeding introduced at a later period in the grower phase.

2. Quantitative (skip-a-day) regime

Cave (1978), using the broiler breeder parent stock, and the basic skip-a-day system during the growing phase maintained body weights at 20 weeks within the range recommended by the breeder supplier. Where labour and time are limited in a practical field operation this method is probably adopted as a compromise to the complex system of monitoring feed allowance to body weights described in, for example, the Hubbard Breeder Manual (1978). For these reasons the skip-a-day system with a wheat based diet was selected as the control regime.

A 20% reduction in body weight at the end of the growing period was slightly better than that obtained with the fibre diet. Feeders were manually lowered on the "on feed" day and eight hours later raised again to be out of reach of the birds. In a large breeder operation this constitutes a major labour demand.

Nevertheless, the clear advantage of feeding 8 in every 48 hours was demonstrated by the two skip-a-day groups in Broiler Breeder Study I. The improved performance of these birds seemed to relate to the delay in sexual maturity, a finding consistent with that of Fuller *et al.* (1970). Summers *et al.* (1967) dismissed the importance of delaying sexual maturity, suggesting that reducing liveweight "at point of lay" was the significant factor. This apparent contradiction could be explained if birds, reaching an optimal weight at maturity, will also perform better when the onset of production is delayed, both effects being independent but additive. The failure of the body weight effect to be expressed in the fibre fed group could be due to other factors

discussed in more detail later.

3. Rye replacement of wheat

The relative performance of the rye fed birds was impressive and consistent throughout the entire trial. The lowest body weights at 20 weeks and the greatest delay in "days to first egg" correlated well with the highest total % hen-day production. In spite of a 20% reduction in body weight the differences found in body conformation were slight and, with the exception of the tibia length, non-significant. Thus the smaller body weight did not adversely affect total body volume.

These results encourage the further investigation of rye grain as a replacement for wheat in both grower and breeder rations for commercial broiler breeder pullet operations.

II. NUTRITIONAL, PHYSIOLOGICAL AND ANATOMICAL EFFECTS OF REARING METHODS

A. General

Information regarding the specific effects of the various restriction methods for growing broiler breeder pullets is very limited. An attempt was made to monitor the influence of the different diets and dietary regimes on organ development. In addition, balance trials during the cockerel and broiler breeder growth (II) studies and the investigation of rates of passage during the latter experiment were expected to provide some insight into the relative performance observed with the four treatment groups.

1. Nutrient balance

Asplund (1979) extensively reviewed the area of nutrient balance trials, commenting on their general methodology and subsequent interpretive significance. Following his recommendations, the studies described here would more appropriately be termed "gross balance", since only fecal and urinary losses are considered. Further, he states that balance trials should only be attempted with a specific atomic species that can be readily identified. This would include nitrogen and minerals; excluding such variable feed constituents as crude fibre, ether extract and ash. The author emphasizes that balance data, when nutrients are fed at above the requirement, reflect the state of the animal rather than the availability of the nutrient in the feed. This is particularly true in poultry where urinary and fecal losses are not easily distinguishable. In long term feeding trials that compare diets or dietary regimes, the state of the animal is a function of the nutrients retained. Therefore the nutrient balance data in the present studies, although not definitive, do give some indication of the relative effects of a feeding programme.

2. Gastrointestinal development

Some researchers (Kondra et al., 1974; Savory and Gentle, 1976a,b) have suggested that fibre feeding might stimulate the development of a more efficient gastrointestinal system and an increased total capacity. The importance of this, particularly with birds going into peak production where the ability to consume enough energy could be limiting, prompted the detailed investigations in this area.

The relevance of the criticisms of Burger et al. (1962) concerning the general understanding of body-organ weight relationships is borne out when the cockerel data are compared using the three methods of statistical analysis (Table 37). Application of the recommended linear regression model gave an intermediate number of significant differences between the two other methods. The bias introduced when body weight differences were ignored was overcompensated for by adjustment using the "Ratio Method". Therefore, regression analysis should be the preferred method.

Simple application of the regression model can also be misleading when comparisons are made over a wide range of body weights. A necessary condition for regression analysis is homogeneity of variance (Snedecor and Cochran, 1967). Cockerel study 3 demonstrates that variance increases substantially with age in all organ measurements determined. Hakansson et al. (1978) avoided this problem by comparing regression lines within narrow weight intervals over the total growth period. Attempts to employ this technique in the Broiler Breeder Pullet Trial (I) failed because of insufficient number of birds selected within each sampling period.

3. Rate of passage

This study was undertaken to determine if fibre in poultry diets would have a similar effect on gastrointestinal passage rates as has been reported in other species and to see if this could be related to the overall performance of these birds during the broiler breeder pullet trial. Feeding of rye grain has recently been found to cause slower rates of passage in young chicks (personal communication with

Table 37. Comparison of significant differences when three methods of statistical analysis of level (% fibre) are compared in cockerels fed pelleted or non-pelleted rations

	Unadjusted		Adjusted		Multiple regression	
Organ	Non-pelleted	Pelleted	Non-pelleted	Pelleted	Non-pelleted	Pelleted
Liver wt.	X[1]	X				
Pancreas wt.		X	X	X		
Provent. wt.			X	X		
Vent. wt.			X		X	X
Duodenum						
Length			X	X		
Wt.			X	X		
Density			X	X		
Jejunum						
Length	X		X	X		
Wt.	X		X	X		X
Density			X	X	X	X
Ileum						
Length			X	X		
Wt.	X		X	X		X
Density			X	X	X	X
Colon						
Length			X	X		
Wt.			X	X	X	X
Density			X	X	X	X
Caecum						
Length			X	X		
Wt.						X
Density						

[1] X indicates a significant difference between fibre levels ($P \leq .05$)

T. Ward, Univ. of Manitoba) and similar studies in older birds could contribute to a better understanding of this grain's general physiological effects.

Chromic oxide was chosen as a marker in these studies because of its close association with the non-digestible material in the gut and the relative simplicity of the assay. This marker was thought to represent more accurately the minimum passage rate of the experimental diets since the water insoluble, non-digested material would move most rapidly through the gut (Bjornhag and Sperber, 1977; Hunt et al., 1978; Mitchell and Eastwood, 1978).

The method described by Jensen et al. (1962) for measuring passage rate was considered most appropriate. It enabled the monitoring of the total pattern of marker excretion while causing the least interruption in the bird's normal routine. The high concentration of chromic oxide (2%) permitted a large dose to be consumed in a short time. A major problem with this technique, discussed by Sibbald (1979), is the association of the marker with the walls of the alimentary tract. Unmarked feed passing through the digestive system would become marked and this, together with any mucosal cells which have been sloughed off, would contribute to the total recovery in the feces. Thus, feed passage measurements would be confused by differing rates of mucosal turnover or differing feed intakes. In the experiments reported here, where at least 40 grams of feed was consumed, the contribution to total fecal output of marked endogenous material would be minimal in the first 12-15 hours. The 20% of chromic oxide not recovered after 48 hours was probably associated with the upper intestinal tract where epithelial

turnover is comparatively slow.

B. Dietary Regimes

1. High fibre

In all trials there was a consistent depression of fat retention with higher levels of added dietary fibre. Akiba and Matsumoto (1978) found that 8% cellulose diets did not affect absorption of total lipids but did cause an alteration in liver lipid metabolism. The trials described here used higher levels of dietary fibre and thus absorption effects could be coupled to changes in the metabolic activity of the liver, the latter being supported by the much smaller liver size for the high fibre treatment group in the Broiler Breeder Trial I (50% smaller than the full fed wheat group at 20 weeks). This might have contributed to the poor layer performance of these birds, since a greater proportion of overall nutrients would have to be directed to fatty acid mobilization and turnover, leaving less available for other egg synthesizing functions.

Another consistent effect of fibre diluted diets was a lower calcium retention. The negative influence of NPPF and cellulose on calcium retention is well documented in the literature (Griffith et al., 1961; Viola et al., 1970; Reinhold et al., 1976; Nwokolo and Bragg, 1977 and Cummings, 1978). This may have played a significant role in limiting egg production particularly in the early breeder phase. Poor bone calcification would lead to low body calcium stores and less developed associated synthetic capacity.

Whether the two effects described above played a significant role in the outcome of the layer period is speculative. The possibility that irreversible changes occur during the first six weeks of growth as a result of feeding high fibre needs further investigation. Thus, the positive results described by Kondra et al. (1974), where fibre feeding during the growing period improved layer performance, were dependent upon the introduction of the diluent during the less rapid phase of development (12 weeks). Detailed studies on lipid metabolism and carcass analysis could provide additional support for this hypothesis.

No effects of added dietary fibre on the length of the intestinal tract were observed. The cockerel study (3) relating age, body weight and G.I. tract growth indicated that development of length, given adequate nutrient intake, is independent of body weight gain. This substantiates the findings of McCance (1974) in pigs and Hakansson et al. (1978) in broiler chickens. Younoszai et al. (1978), studying intestinal growth in rats, compared the effects of a purified diet devoid of crude fibre with conventional and semi-purified rations and found increases in development of intestinal length with the latter two diets. Differences in the small intestine were small (less than 8%) while those in the colon were more substantial (greater than 35%). Even with highly digestible diets, very little influence of small intestinal length development was detected. Two other groups described increase in total gut length with fibre feeding. Kondra et al. (1974) used the "Ratio Method" of analysis which introduced a bias favoring longer organ lengths with the smaller, fibre-fed birds. For example, when means for adjusted small intestine lengths (cm/kg body weight) are multiplied by the mean body weights of each treatment, the differences between dietary groups are

small: 150.4 cm for the high fibre group versus 147.7 cm for the control group. Savory and Gentle (1976) used covariance analysis, at any stage of bird (quail) development. The problem with this is particularly apparent with adult birds where there is no evidence that organ length is influenced by changes in body weight.

Large and significant responses to increased dietary fibre occurred in the weight of the ventriculus and distal section of the intestinal tract. Similar findings were reported by Hollands et al. (1965), Kondra et al. (1974), Savory and Gentle (1976b) and Hakansson et al. (1978). Changes in the upper tract could be related to increased muscular development to cope with higher levels of coarse, non-digestible material. An adaptive increase in overall capacity of the ventriculus in response to fibre would help explain the ability for higher intakes with consumption of lower energy diets. Increases in the lower G.I. tract, particularly the terminal ileum and colon, could be related to two factors: increased muscle thickness to assist expulsion of a bulky, low moisture feces and increased microbial activity which has been shown to stimulate intestinal growth (Topping and Visek, 1977).

The influence of microbes in the lower gut and the results of the rate of passage study contribute to a possible explanation of the improved basal feed utilization observed with the fibre diluted diets during the Broiler Breeder Growth Studies. The rapid rates of recovery of chromic oxide with the fibre fed birds was dependent upon the availability of feed. When the food was removed during the dark period the rates rapidly declined to those found with the full fed wheat group. This is consistent with a report by Sibbald (1979). Rapid transit times when

feed is available permitted greater basal intake, a finding in general agreement with studies by Bjornhag and Sperber (1977). When food was removed, however, the declining passage rate would permit more complete breakdown of the less digestible material; possibly making the limited nutrients in wheat straw more available.

2. Quantitative (skip-a-day)

a) Wheat soy diets

No significant effects in nutrient retention or gastrointestinal development were found with the wheat based skip-a-day feeding system when compared to the full fed wheat diet. Reduction in growth during the growing phase of Broiler Breeder Study I could be directly attributed to an equivalent depression in energy intake. This reflects the physical inability of the restricted birds to consume in 8 hours the same amount as the full fed birds consumed in 16 hours. Alternatively, the hypothesis of Scott (1980), that birds exposed to energy limiting conditions will consume enough for normal growth but not excess fat deposition, may be important.

The poorer feed to gain ratio found in Broiler Breeder Study II, but not in Study I, with the restricted birds simply reflected the severity of the treatment. Intake for maintenance requirements represented a much greater proportion of total feed intake than that found with the full fed group.

The rate of passage study indicated that with the skip-a-day system transit times were much slower than with the full fed groups. This was, at least initially, independent of feed intake since no dif-

ferences in intake between groups occurred in the first 1½ hours. The subsequent decline in feed consumption with the restricted treatments probably related to the much smaller capacity of their upper digestive tract and would not be a characteristic of the less severe skip-a-day system used in Broiler Breeder Study I. The relevance of this adaptation (i.e. slower rates of passage during the grower phase) to the subsequent superior performance (% hen-day) during the layer phase is questionable.

The improved performance of the restricted birds did not have any obvious physiological or nutritional basis. Possibly the repression of behavioural patterns (social order etc.) with the skip-a-day system (Lewis, 1978), given adequate feeder space, permits a greater number of birds to reach optimal weights by maturity while delivering an adequate concentration of nutrients for normal organ development. This latter point can be illustrated when comparing 20 wk liver weights. The restricted group, in spite of a 20% decline in body weight, had only 13% smaller liver weights than the full fed group. This is in contrast to the high fibre birds who, with similar body weights, had 50% smaller liver weights.

b) Rye replacement of wheat

A tendency towards lower fat and protein retention with the rye fed birds is supported by recent, more detailed studies, (Antoniou, 1980). The failure for this trend to reach significance relates to: the skip-a-day feeding system which would optimize nutrient availability, and the low level of rye (40%) used in the grower diets. Nevertheless, these subtle effects may be responsible for the slight

growth reduction with the rye fed birds in Broiler Breeder Study I.

The effects of rye feeding on the gastrointestinal tract were to cause a more general increase in weight and density than that found with the wheat straw group. Although Antoniou (1980) reported an increase in length of the small intestine with rye diets when analyzed using the "Ratio Method", the increase in weights was more dramatic. Brown et al. (1979) described a similar pattern in rats fed pectin supplemented rations. That these effects are related to a stimulated microfloral population (Topping and Visek, 1977) is supported by the significant and consistent (through the 3 sampling periods) increase in caecum length, weight and density. The high levels of water soluble hemicelluloses in rye diets (Antoniou, 1980), would readily enter the caecum and stimulate the development of this tissue, where bacterial activity and water resorption processes predominate (Thornburn and Willcox, 1965).

Rye feeding caused slower rates of passage when compared to the wheat based diets. On the skip-a-day system this would have a minimal influence on feed intake because of the 40 hours between feedings. Similarly, the effect of passage rate on general performance characteristics is probably minimal.

SUMMARY AND CONCLUSIONS

Preliminary studies were conducted with SCWL cockerels to determine the effect of fibre diluted diets on growth and nutrient intake. The information obtained was then applied to the formulation of broiler breeder starter and grower diets so that they would, theoretically, be as effective as the quantitative systems for controlling growth. The skip-a-day system was used as a control and included two diets, one wheat-soy based and the other containing 40% rye grain as replacement of wheat. Subsequent breeder performance was evaluated based upon the influence of the grower regimes.

Concurrently, with the performance data collected on all trials, the influence of the grower regimes on nutrient balance, gastrointestinal development and rate of passage was determined and the results related to overall performance.

The data derived from these experiments led to the following observations and conclusions:

1. a. High fibre diets were as effective as the skip-a-day system for controlling growth of broiler breeder pullets to 20 weeks of age.

b. Inclusion of 30% wheat straw did not, however, result in the 30% reduction in weight gain predicted by the cockerel data. This occurred because of two age-dependent factors: an increased capacity for food consumption of these birds when compared to the wheat-soy diets and in improvement in basal feed utilization.

c. The increased capacity for feed intake with the high fibre groups is related to the increased volume of the upper alimentary tract (ventriculus) and the high rates of passage during the day (when feed is

available) observed with high fibre feeding.

d. The improved apparent feed utilization may be a function of the increased availability of the less digestible components (i.e. wheat straw) of the diet through greater microbial activity as evidenced by the size of the colon and terminal ileum. The slower rates of passage during periods of food removal (dark periods) would also facilitate this fermentative process.

2. In spite of significant differences of broiler breeder weights between the dietary regimes at 22 weeks, no differences in overall body size were apparent as indicated by body conformation measurements.

3. a. Performance during the layer phase for the fibre fed birds was poor and comparable to the full fed wheat birds in spite of the 18% reduction in body weight at 20 weeks for the former group.

b. Irreversible changes in the potential for lipid synthesis and/or changes in mineral metabolism may be responsible for the poor production.

c. High fibre dilution of starter and grower rations as a means for early growth restriction of broiler breeder pullets is not recommended.

4. a. The skip-a-day system, while reducing body weight gain to 20 weeks and delaying sexual maturity by 7 days resulted in the best overall performance.

b. No obvious nutritional, physiological or anatomical effects were observed to explain these results.

5. a. Inclusion of rye grain at 40% of a grower ration for broiler breeder pullets resulted in the greatest reduction (22%) in live weight at 20 weeks and the longest delay (9 days) in sexual maturity.

b. This growth data correlated well with the egg production phase where the rye group performed better than all other groups.

c. The negative influence of rye on nutrient retention, rate of passage and feed intake is minimized under the skip-a-day feeding system. Adaptive responses to rye grain were notable in the intestinal tract, particularly the caecum.

6. a. Comparison of three methods of statistical analysis of organ measurements indicated that when significant body weight effects are also apparent, a regression model should be employed. When using this technique with the cockerel experiments, high fibre feeding was found to increase the weight of the ventriculus, the distal section of the small intestine and the colon.

b. Examination of intestinal length development with age and body weight indicated that it is rapidly completed (5-9 weeks) and appears to be substantially independent of functional stimuli. Weight development is more gradual and can be influenced by diet.

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A P P E N D I C E S

Appendix A

Statistical Tables

The mean squares from the analysis of variance tables for all experiments are shown on the following pages.

Appendix Table 1. Mean squares from analysis of variance table of fibre level on growth and feed intake of cockerels fed non-pelleted diets

Source	df	Weight gain	Feed intake	Feed/gain ratios	
				As fed	Basal
Fibre type	1	393.66	68.68	.0376*	.0294*
Fibre level	3	3889.89**	2886.29	.1881**	.0030
Fibre type x fibre level	3	84.45	211.82	.0063	.0043
Error	16	287.30	1296.61	.0080	.0072

*Indicates means squares are significant ($P \leq .05$).

**Indicates means squares are significant ($P \leq .01$).

Appendix Table 2. Mean squares from analysis of variance table of fibre type and fibre level on nutrient retention of cockerels fed non-pelleted diets.

Source	df	Dry matter	Nitrogen	Ether extract	Crude fibre	Calcium	Phosphorus
Fibre type	1	29.70	50.34	107.82	344.51*	564.73*	5.41
Fibre level	3	173.90**	255.16	95.93	2264.07**	146.69	145.93**
Fibre type x fibre level	3	56.03*	374.62*	154.50	365.53**	218.05	92.81*
Error	16	12.95	85.54	66.13	42.98	71.29	23.41

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 3. Mean squares from the analysis of variance table of week, fibre type and fibre level on unadjusted G.I. tract measurements in cockerels fed non-pelleted diets

Source	df	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Duodenum			Jejunum			Ileum			Colon			Caecum			Body weight
							Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	
Week	2	363.84**	1.24**	8.79**	15.79**	413.15**	121.51**	13.80**	18245.8**	692.14**	50.21**	19222.3**	1325.69**	46.04**	14998.0**	19.87**	3.73**	71219.9**	576.06**	19.64**	17.29**	636149.0**
Fibre type	1	0.26	.00	.03	.06	2.43	2.48	.09	6.3	26.95	.09	10.4	.28	.04	24.6	.02	.00	113.1	16.52**	.41	8.86	163.0
Fibre level	3	5.40**	1.01	.02	.07	1.16	.97	.06	82.2	31.20**	.59**	142.6	24.88	.41**	101.5	.09	.01	264.2	1.74	.10	6.13	11887.8**
2-way interact.	11	0.68	.01	.01	.02	.58	.80	.06	281.2	4.67	.23	107.3	5.68	.05	27.6	.30	.02	510.4	2.41	.09	2.01	1344.8*
3-way interact.	6	0.84	.01	.02	.05	.87	1.18	.08	135.8	2.36	.20	122.6	8.85	.10	48.3	.33	.01	282.2	2.19	.16	2.40	1771.2**
Error	120	0.64	.01	.04	.03	.72	1.49	.10	266.0	7.50	.13	88.1	7.77	.10	41.3	.33	.01	362.5	2.45	.11	2.39	564.9

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 4. Mean squares from the analysis of variance table of week, fibre type and fibre level on adjusted G.I. tract measurements in cockerels fed non-pelleted diets

Source	df	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
							Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density
Week	2	102.41**	.73 *	22.93**	57.13**	1182.2**	70915.1**	613.86**	4433682.0**	306830.8**	492.74**	1026607.0**	271857.8**	96.45**	387728.1**	6281.47**	5.95**	1073629.0**	44779.7**	17.29**	26822.3*
Fibre type	1	4.76	.25	0.18	.53	11.95	35.2	.27	4818.1	719.4	2.11	2026.1	2.38	3.01	3957.8	1.57	.23	13799.1	232.4	8.86	268.4
Fibre level	3	15.52	.13	4.89**	5.26**	505.80**	1845.8**	19.29**	94205.1**	5160.0**	19.48**	42116.9**	5419.5**	9.63**	19002.0**	207.20**	2.24 **	102916.2**	1856.5**	6.13	200.2*
2-way interact.	11	4.82	.27	.17	.21	13.65	130.9	1.24	6405.8	555.2	3.21	2767.5	633.2	1.37	1292.8	16.56	.29	15887.2	158.3	2.01	194.2
3-way interact.	6	9.62	.11	.21	.77	9.30	219.4	2.28	9837.0	1270.5	1.18	928.2	921.6	.49	406.9	3.75	.21	9392.7	165.2	2.40	100.6
Error	120	7.02	.23	.60	.45	17.77	139.4	2.69	11725.4	609.1	2.42	2188.2	472.1	1.23	1173.2	18.46	.24	11500.9	114.5	2.39	119.7

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 5. Mean squares[1,2] of multiple regression analysis of G.I. tract measurements in cockerels fed non-pelleted diets

Source	df	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
							Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density
Saturated model	7	.13342**	.08394**	.12006**	.13175**	.13118**	.08287**	.10469**	.08048**	.08718**	.12946**	.11819**	.10441**	.13109**	.12651**	.06880**	.12181**	.10937**	.11011**	.10758**	.07835**
Additive model	4	.23349**	.14149**	.20751**	.22915**	.22665**	.14484**	.18064**	.13420**	.14903**	.22407**	.20508**	.18181**	.22920**	.22058**	.11883**	.21307**	.19096**	.19101**	.18424**	.13198**
i) Adjusted for body weight	3	.00065	.00152	.00554	.00233**	.01314**	.00233	.00170	.00139	.00391	.00163	.00435*	.00059	.00094	.00309*	.00429	.00484**	.00530*	.00275	.00354	.00315
ii) Adjusted for gut size	1	.91017**	.56123**	.82727**	.91125**	.90286**	.57281**	.71798**	.53339**	.55823**	.88176**	.81198**	.70744**	.90540**	.87384**	.47231**	.85061**	.75974**	.76056**	.73142**	.52216**
Interaction	3	.00144*	.00720	.00346*	.00187*	.00055	.00024	.00342	.00886	.00471	.00330**	.00234	.00121	.00028	.00108	.00208	.00012	.00059	.00225	.00536*	.00684
Residual	136	.00049	.00303	.00117	.00057	.0006	.00309	.00197	.00321	.00287	.00069	.00127	.00198	.00061	.00084	.00308	.00108	.00172	.00169	.00182	.00332

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 6. Mean squares from analysis of variance tables of fibre type and fibre level on growth and feed intake of cockerels fed pelleted diets

	df	Weight gain	Feed intake	Feed/gain ratios	
				As fed	Basal
Fibre type	1	6.83	2.81	.0003	.0001
Fibre level	3	2989.64**	2625.12	.2348**	.0079
Fibre type x fibre level	3	57.13	397.72	.0009	.0008
Error	16	342.79	1409.47	.0039	.0029

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 7. Mean squares from analysis of variance tables of fibre type and fibre level on nutrient retention of cockerels fed pelleted diets

Source	df	Dry matter	Nitrogen	Ether extract	Crude fibre	Calcium	Phosphorus
Fibre type	1	24.37**	14.82	9.73*	105.84	145.29**	7.12
Fibre level	3	182.44**	22.71	30.79**	58.80	48.37**	29.59
Fibre type x fibre level	3	15.21**	38.10	3.59	31.76	110.11**	35.65
Error	16	.31	20.08	1.39	32.18	5.29	23.05

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 8. Mean squares from the analysis of variance tables of week, fibre type and fibre level on unadjusted G.I. tract measurements in cockerels fed pelleted diets

Source	df	Body weight	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Crop weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
									Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Densi
Main effects	5	50967.5**	23.7**	.007**	.33**	.83**	14.35**	1.11**	7.15**	.49**	997.8**	41.61	2.05**	705.8**	126.6**	2.30**	612.1**	.22	.19**	6815.5**	28.76**	2.59**	3860.4
Week	1	236215.0**	109.0**	.031**	1.23**	3.92**	70.74**	4.97**	27.19**	2.34**	2743.6**	197.21	10.02**	3151.1**	622.2**	10.69**	2075.5**	.40	.89**	32506.7**	139.67**	12.67**	18796.0
% fibre level	3	5942.9**	2.4**	.0001	.11*	.06	.31	.18*	.66	.02	334.6	2.88	.06	116.0	2.2	.03	65.9	.09	.01	454.5	1.13	.02	68.4
Fibre type	1	793.5	1.9*	.0001	.10	.07	.07	.06	6.57	.01	1241.6*	2.22	.06	30.1	3.9	.72**	787.4**	.45	.0001	207.3	.73	.19	300.1
2-Way interact.	7	1503.7*	1.3**	.0020	.01	.13*	.56	.08	.84	.12	294.9	5.03	.36	247.4	8.9	.07	63.7	.14	.02	652.6	2.77	.34	537.3
3-Way interact.	3	241.6	.11	.0040	.07	.06	.68	.03	1.01	.03	196.8	2.71	.09	73.8	6.3	.07	50.3	1.32*	.01	457.5	4.87*	.39	333.5
Error	80	549.8	.35	.0010	.03	.05	.79	.06	1.69	.09	288.1	8.86	.20	146.4	9.9	.10	102.6	.42	.02	557.9	1.71	.22	1604.

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 9. Mean squares from the analysis of variance tables of week, fibre type and fibre level on adjusted G.I. tract measurements of cockerels fed pelleted diets

Source	df	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Crop weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
								Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density
Main effects	5	16.66**	.020	6.01**	5.63**	134.20**	5.77**	2243.1**	29.9**	.22**	10239.3**	45.9**	.073**	7100.1**	14.4**	.036**	312.9**	1.31**	.054**	2091.8**	4.24	.017*
Week	1	62.78**	.029	20.59**	23.63**	400.91**	1.48	10416.6**	122.5**	.89**	46770.7**	161.5**	.293**	30676.7**	27.9**	.134**	1400.6**	1.59*	.102**	8706.2**	1.68	.039*
% fibre	3	5.10	.023	2.80**	1.48	89.79**	9.01**	253.2**	8.3**	.05**	1370.5**	20.1**	.023**	1462.5**	12.8**	.013**	47.8**	1.58**	.056**	559.0**	4.53	.011
Fibre type	1	5.23	.002	1.05	.07	.74	.36	39.3	2.1	.04**	314.5	8.0*	.004	436.2	5.6*	.009*	20.3	.23	.000	75.6	5.90	.010
2-Way interact.	7	4.52*	.026	.88	1.18	5.60	2.26	67.0	3.1*	.01	222.8	5.4**	.005**	107.1	1.3	.003	7.5	.36	.012	25.3	4.24	.009
3-Way interact.	3	.12	.067*	1.07	.62	15.61	.57	2.6	.6	.01	93.4	3.2	.003	266.5	2.5	.001	21.8	.18	.013	33.6	2.90	.001
Error	80	2.13	.020	.53	.57	9.14	1.09	49.2	1.3	.01	247.7	1.8	.002	298.5	1.0	.001	9.2	.25	.009	38.6	2.38	.006

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 10. Mean squares of multiple regression analysis of G.I. tract measurements in cockerels fed pelleted diets

Source	df	Liver weight	Gall blad. weight	Pancreas weight	Provent. weight	Ventric. weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
							Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density
Saturated model	7	.13134**	.03806**	.06974**	.09085**	.09307**	.03860**	.06146**	.03484**	.04228**	.08465**	.05797**	.06043**	.10205**	.05068**	.00421	.07103**	.06845**	.08725**	.07089**	.05753**
Additive model	4	.22945**	.06183**	.10992**	.15727**	.16103**	.05771**	.09325**	.05274**	.06678**	.14610**	.09482**	.10367**	.17455*	.07847**	.00704	.11927**	.011369**	.15153**	.11618**	.09253**
i) Adjusted for body weight	3	.00077	.01062	.03101**	.00386	.01722**	.00144	.00983	.02037	.00152	.01742**	.02432**	.00331	.02271**	.02046*	.00351	.02737**	.02506**	.02048**	.01038	.00593
ii) Adjusted for gut size	1	.87068**	.23922**	.36561**	.60816**	.63723**	.21974**	.36640**	.17826**	.25812**	.57867*	.35905*	.41021**	.69331**	.29723**	.02170	.46067**	.43864**	.59530**	.46292**	.36670**
Interaction	3	.00053	.00636	.01617*	.00228	.00247	.01312	.01907*	.01096	.00962	.00273	.00884	.00278	.00540	.01362	.00045	.00672	.00814	.00155	.01049	.01088
Residual	88	.00092	.00834	.00582	.00414	.00396	.00829	.00648	.00859	.00800	.00463	.00675	.00656	.00325	.00733	.01103	.00571	.00592	.00422	.00573	.00679

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 11. Mean squares from analysis of variance tables of growth and feed intake of broiler breeder pullets during the growing phase

	df	Weight gain	Total feed intake	Feed efficiency
Diet	3	.737**	28.58**	1.94**
Error	17	.023	0.30	.03

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 12. Mean squares from the analysis of variance tables of unadjusted (A) and adjusted (B) measurements of body conformation of broiler breeder pullets at 22 weeks

A. Unadjusted

	df	Weight	Circum-ference	Keel	Body length	Tibia
Diet	3	.80*	8.22	1.92	1.65	2.97*
Error	36	.20	12.49	.76	3.63	1.02

B. Adjusted

Diet	3	-	3.19	.48	1.59*	.17
Error	36	-	1.40	.19	.47	.18

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 13. Mean squares from analysis of variance tables of unadjusted G.I. tract measurements over three sampling periods in growing broiler breeder pullets

Week	Source	df	Body weight	Liver weight	Pancreas weight	Proventric. weight	Ventric. weight	Duodenum			Jejunum			Ileum			Colon			Caecum		
								Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density	Length	Weight	Density
6	Treatment	2	0.121**	103.04*	.07	.14	267.08*	60.60	16.85*	.0062*	440.94*	26.13*	.0003	234.90*	5.56	.0001	9.46*	1.91	.0052	24.85	7.57*	.0072**
	Error	39	0.010	17.87	.17	.50	10.00	7.39	1.28	.0015	47.85	3.02	.0007	42.96	1.92	.0005	1.49	.15	.0032	8.88	.34	.0003
15	Treatment	3	1.57**	414.20*	3.30*	6.53*	734.56*	15.55	22.18*	.0131**	53.68	145.64	.0183	66.39	18.16	.0017	3.49*	.76	.0091	8.97	21.01*	.0181**
	Error	28	.05	41.91	.72	.95	216.87	20.36	3.26	.0029	53.41	99.86	.0147	36.05	11.58	.0022	2.56	.85	.0039	15.72	2.08	.0026
20	Treatment	3	1.18**	986.0 *	.81	.97	315.5*	19.45	6.69	.0032	186.05	24.82	.0045	68.23	6.95	.0004	6.03	.68	.0332	36.09	24.45*	.0084**
	Error	19	.12	230.0	.86	1.29	238.8	10.14	3.40	.0031	100.10	18.35	.0020	82.08	6.90	.0012	1.97	.85	.0127	16.20	2.00	.0008

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 14. Mean squares from analysis of variance tables of adjusted G.I. tract measurements over three sampling periods in growing broiler breeder pullets

Week	Source	df	Liver weight	Pancreas weight	Proventric. weight	Ventric. weight	Duodenum		Jejunum		Ileum		Colon		Caecum	
							Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight
6	Treatment	2	410.61**	1.59**	3.12**	137.17**	351.69**	45.66**	2289.8**	106.13**	1756.9**	36.79**	6.28	1.00**	295.44**	18.39**
	Error	39	9.46	.16	.33	7.70	14.01	1.05	99.7	1.54	91.6	1.33	2.66	.10	23.22	.36
15	Treatment	3	17.66**	.035	1.12**	288.71**	12.34**	2.21**	74.20**	22.66	94.22**	4.06**	3.17**	.56**	24.07**	3.15**
	Error	28	3.72	.052	.13	28.55	2.43	.28	5.05	9.32	4.21	.93	.34	.09	1.54	.51
20	Treatment	3	26.91	.186**	.254**	94.63**	1.94	.656	58.40**	3.51*	30.54**	2.32**	.075	.265	8.78*	2.34**
	Error	19	10.12	.037	.070	18.69	1.02	.286	7.85	1.27	6.63	.42	.229	.088	1.91	.22

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 15. Mean squares from the analysis of variance tables of the effect of grower diets of broiler breeder pullets on subsequent layer performance

		Days to first egg				Egg production				
	df	4 treatments	df	2 treatments	df	4 treatments	df	2 treatments	df	Egg weight
Diet	3	98.50	1	252.0*	3	119.0	1	308.1*	3	3.52*
Error	16	46.70	18	42.6	16	56.7	18	53.1	16	1.08

*Indicates mean squares are significant ($P \leq .05$).

Appendix Table 16. Mean squares from analysis of variance tables of broiler breeder pullets on hatchability during the layer phase

Source	df	% of all eggs	% of fertile eggs
Treatment	3	363.14	51.05
Error	16	270.72	69.62

Appendix Table 17. Mean squares from analysis of variance tables of growth and feed intake of broilers fed to 7 weeks

	df	Average wt. gain	Feed consumption	Feed/gain
Diets	3	235456.4**	2663489.5**	1.81**
Error	12	1337.2	9232.7	.18

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 18. Mean squares from analysis of variance tables of the effects of grower diets on nutrient retention

	df	Dry matter	MEn	Nitrogen	Ether extract	ADF	Feed intake
Diets	3	171.95**	279533.0**	11.50	65.95	385.70*	1705.0**
Error	8	17.38	22084.0	13.40	18.65	86.80	39.7

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 19. Mean squares from the analysis of variance tables for the effect of grower diets on mineral retention

Source	df	Sodium	Potassium	Calcium	Magnesium	Phosphorus
Diets	3	307.8	81.1	779.3**	44.4	153.5
Error	8	106.8	171.0	94.2	51.7	44.4

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 20. Mean squares from the analysis of variance tables of feed intake and marker recovery in broilers during the rate of passage study.

	Marker-feed intake	Normal intake	Total intake	Total marker recovery (%) after 48 hours	Body weight
Diet	10.6	731.7**	704.8**	17.0	250382.6**
Error	49.2	5.2	5.2	59.9	4635.3

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 21. Mean squares from analysis of variance tables of cummulative chromic oxide recovery at specified intervals (hours) after introduction of the marker diet

	df	3	4	5	6	7	8	10	14	Mean
Diet	3	55.9**	221.7**	333.7**	377.6**	373.3**	402.0**	418.2**	514.4**	221.1**
Error	8	3.2	3.7	15.1	21.5	39.3	49.5	64.0	57.8	24.6

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix Table 22. Mean squares from the analysis of variance tables of change in dry matter content of fecal output with time during the rate of passage study

	df	12:00	13:00	14:00	15:00	16:00	17:00	19:00	23:00
Diet	3	73.2	157.9*	148.3**	279.3**	123.9**	77.6	42.8	19.9
Error	8	37.5	25.2	15.0	7.2	15.3	19.0	15.1	28.1

*Indicates mean squares are significant ($P \leq .05$).

**Indicates mean squares are significant ($P \leq .01$).

Appendix B

Multiple Regression Analysis of Cockerel Gut Size Data.

A comprehensive computer programme described by Kim and Kohout (1975) combining multiple regression techniques with the use of dummy variables enabled a complete characterization of the relationship between organ development and body weight gain as influenced by fibre level in the diet.

The multiple regression model can be described by:

$$\hat{Y} = A + B_1D_1 + B_2D_2 + B_3D_3 + B_4X + B_5(D_1X) + B_6(D_2X) + B_7(D_3X)$$

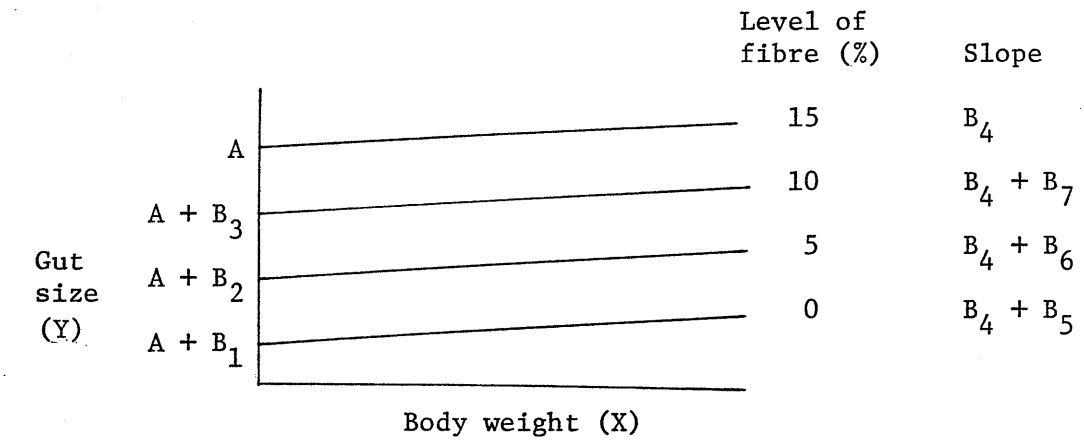
where: $\hat{Y}$ = the predicted gut size and

X = body weight

The dummy variables (D_1 to D_3) are created as illustrated by the matrix:

	Dummy variable		
Level of fibre (%)	D_1	D_2	D_3
0	1	0	0
5	0	1	0
10	0	0	1
15	0	0	0

such that:



For example if level of fibre is 15%; then D_1, D_2 and D_3 equal 0 and $\hat{Y} = A + B_4X$. Therefore a separate regression equation can be developed for each level of fibre. By examining fibre level effects and body weight effects (ADDITIVE MODEL), interactions between fibre level and body weight, and relating the contribution of each (using regression coefficients) to the whole model (SATURATED MODEL) one can answer the following questions:

1. Does knowing the fibre level and body weight help predict gut size or is the Saturated Model significant?
2. Do the different levels of fibre have the same slope or is there significant interaction?
3. Does body weight have an effect when differences in fibre level are controlled?
4. Does fibre level have an effect when differences between body weights are controlled?