MITIGATION OF POULTRY MANURE POLLUTION IN THE FRASER VALLEY:

A STUDY OF DIET AND MANURE DISPOSAL STRATEGIES

by

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ABSTRACT

Intensive poultry production in the lower Fraser Valley of British Columbia has resulted in large quantities of poultry manure being spread on limited land space. This manure is spread on land situated above the Abbotsford aquifer. Due to the high amount of nitrogen and phosphorus present in poultry manure, there is a danger of these nutrients leaching into the groundwater of the aquifer as nitrates. High levels of nitrates in drinking water have been linked to various health hazards such as Methemoglobinaemia, stomach cancer, and gastric cancer. The leaching problem is further compounded by the fact that the region has porous soils, a high water table, and very high annual rainfall.

This problem was addressed by analyzing several dietary treatments having varying levels of crude protein from a high of 25% CP (crude protein) to a low of 18% CP and supplemented with the commercial amino acids L-LYS, DL-MET, L-THR, and L-TRY. A linear programming model was used to determine the least cost diet from the various dietary treatments. The most efficient dietary treatment was then identified by Manure disposal options such as storage, land application, and transportation were also considered along with their associated costs. Linear programming was used to identify the least cost manure disposal strategy complying with British Columbia environmental regulations by using a combination of the three options. The results from the two models above were then combined to identify the optimum manure management strategy for a poultry farm in the Fraser valley complying with environmental regulations.

The results indicate that diets containing lower levels of crude protein and supplemented with amino acids costs less than those containing higher levels of crude

protein. These diets perform better because the nitrogen in the protein is utilized more efficiently thereby resulting in less nitrogen excretion in the manure. Manure that contains low amounts of nitrogen costs less to dispose than that having high amounts of nitrogen. Use of diets containing low levels of crude protein and supplementing them with commercial amino acids can lower the costs of poultry farmers significantly while complying with environmental regulations.

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CHAPTER 1

INTRODUCTION

1.1 Intensive Agriculture and Environmental Pollution

The past few years have experienced a growing awareness of environmental problems associated with intensive agricultural practices. Agricultural inputs such as fertilizers and agricultural by-products such as livestock manure are a cause of concern due to their disposal methods and their environmental impacts. The major concern regarding animal pollution stems from the excessive amount of manure produced and applied on the land as fertilizer or stored on the farm under uncovered conditions. The manure is applied onto the land as a fertilizer because it contains various nutrients that are beneficial for crop growth and also for its good soil conditioning properties. The prominent nutrients in the manure are nitrogen (N), phosphorus (P), and potassium (K). This manure has relatively high levels of nitrogen and phosphorus due to the high amounts of these nutrients in the animals' diets. Poultry manure has relatively higher levels of these nutrients than other farm animals.

Nutrient levels in manure can vary considerably depending upon composition of the diet fed to the animals, system and length of manure storage, and the amount of water, bedding, or feed spillage in the manure. Table 1.1 below illustrates how different types of birds can have such varying levels of nutrients in the manure. Each type of bird has a different diet and different type of manure storage system. The system and length of manure storage primarily affects the nitrogen content of manure while phosphorus and potassium are not lost prior to land application unless there is runoff from an uncovered feedlot. Nitrogen management presents a greater challenge to the farmer than any other nutrient because no other nutrient leaves or enters the plant-soil system by more routes than nitrogen. When manure is applied on the land surface, nitrogen loss by volatilization is rapid and most of the ammonia nitrogen loss occurs within 48 hours after application. There is also considerable loss of nitrogen when manure is stored and this may range between 10% and 50 % of the excreted amount (Moon et al, 1994).

Table 1.1: Nutrient Content of Poultry Manure

Poultry Type	Nitrogen	Phosphate (P_2O_5)	Potash (K_2O)
	kg/tonne		
Broiler Chicken	34.7	25.0	13.4
Roaster Chicken	48.5	36.4	14.6
Layer Pullets	30.9	29.8	11.0
Broiler Turkey	37.3	35.1	15.7
Heavy Tom	26.6	21.1	11.3
Heavy Hen	30.9	32.1	14.3

Source: Sustainable Poultry Farming Group (SPFG), 1994.

Recent reports indicate that agriculture is one of the largest contributors to water pollution and animal production plays a significant role in this (Sutton, 1994). Water pollution from animal wastes occurs primarily by direct runoff after field application of manure, by contaminated water from open feedlots, or from leaching caused by excessive manure application to the land. The problem of groundwater pollution arises when surplus nutrients are not taken up by crops and get leached from the root zone into the groundwater. The major nutrients of concern with regards to water pollution are nitrogen and phosphorus

1.1.1 Human Health Concerns From Water Nitrates

The presence of high levels of nitrogen in drinking water is associated with human health problems. This has worried scientists for a long time and prompted several studies in this field. There is some epidemiological evidence associating high levels of nitrates in drinking water with stomach cancer, although this link is still controversial (Hanley, 1990). According to O'Riordan and Bentham (1993) in Mansoor (1994) a positive correlation between nitrate intake and the occurrence of stomach cancer is prevalent. The same study has cited similar associations between gastric cancer and nitrate ingestion in various countries.

In normal healthy individuals, nitrates are rapidly adsorbed by the gastro-intestinal tract, however, infants especially up to three months old cannot assimilate nitrates since the enzymes which are responsible for the reduction of nitrates are not fully developed. Levels of 10 mg/L of nitrate-nitrogen in drinking water have been linked to Methemoglobinaemia or "Blue Baby Syndrome", an illness caused by oxygen starvation in bottle-fed infants (Hanley, 1990). Cases of clinical methaemoglobinaemia and hypertension have also been reported in school-aged children in regions that have high levels of nitrates in drinking water (WHO, 1977). High levels of nitrates and phosphates in water promote the growth of algae (eutrophication) whose decay depletes oxygen levels in water (Haley, 1990).

1.1.2 Soil Nitrogen Cycle

To understand the processes involved in nitrate accumulation, a basic understanding of the soil-nitrogen system is necessary. Analyzing the chemical and physical processes is fundamental in the search for practical solutions to the problem.

On contact with moist soil, the nitrogen in manure that is incorporated in the soil is quickly converted to nitrate-nitrogen (NO_3^-) by the process of nitrification. Nitrate-nitrogen does not react to a significant extent in the soil and hence moves freely in the soil water and can be adsorbed by plants, can be leached out of the root zone into the groundwater, or can be denitrified thereby resulting in a gaseous loss (Chipperfield, 1994). Since poultry manure has the highest concentration of nitrogen relative to other farm animals, the intensive production of poultry and subsequent large volume of manure creates a potential source of nitrate leaching through land application. To minimize the leaching of nutrients, particularly nitrate-nitrogen, (NO_3^-) and to avoid contamination of groundwater, the rate of manure to be applied on the land should be based on:

(i) the nutrient composition of the manure

(ii) the nutrient requirements of the particular crop in relation to the nutrient supply in the particular soil, and

(iii) the land base available for growing crops.

To achieve this, a farm should have sufficient storage capacity for the manure and sufficient land so as to apply the manure at the correct time and at optimum rates. The challenge of nutrient application is to have nutrients available at the stage of growth when the plant needs them most, therefore manure should be applied in the spring just prior to the growing season or if applied in the fall after harvest, a cover crop should be used to take up the nutrients. As most nitrates are lost from the soil in the autumn and winter, it is important to minimize the amount of nitrates remaining in the soil after harvesting arable crops. Experiments suggest that applying manure to a well established cover crop, rather than bare ground, could reduce leaching and therefore lengthen the period for application (Sutton, 1994). Livestock and poultry producers should therefore consider manure management systems that control and utilize manure nutrients efficiently and are environmentally sound.

1.2 Problem Statement

The British Columbia poultry industry is characterized by intensive chicken production in a region that has a restricted land base. This region also lies above an aquifer that has a high water table and soils that are well to rapidly drained. The region is also characterized by high rainfall (approximately 1500 mm/year).

The high concentration of poultry production in this region results in the production of a high volume of manure and therefore high levels of nitrogen. Most of the manure is spread on the restricted land base as a fertilizer at exorbitant rates, thereby becoming a potential pollutant to the water table.

A new *Code of Agricultural Practices for Waste Management* does not permit uncovered field storage of manure during the winter months and also does not allow the application of litter during the high rainfall months (October to March). This means that the traditional means of spreading all the manure on the adjacent land as a fertilizer will no longer be acceptable under the new code.

Alternative options to reduce the risk of nitrogen pollution due to the large volume of manure produced will have to be considered. There are several options available but each one has different associated costs and attributes. Some of the options can be implemented easily at the farm level but others are more costly and require considerable financing that an individual farmer cannot afford. It is therefore important to consider an option or combination of options that comply with the environmental standards and are also feasible and affordable to an individual farmer in the Fraser Valley.

1.3 Objectives

The primary objective of this thesis is to identify the least cost strategy of manure management that complies with the *Code of Agricultural Practices for Waste Management* for an average poultry farm in the Fraser Valley. This strategy should be feasible and relatively affordable for an average farmer in the Fraser Valley. This objective will be achieved by considering the following sub-objectives:

1. Determine a least cost feeding strategy for poultry using data from experiments designed and carried out by Drs. Blair and Jacobs of the Department of Animal Science at UBC. These experiments reduce manure nitrogen and phosphorus by lowering the levels of crude protein in the diet and using supplemental amino acids in the diets and by the use of feed enzymes.

2. Determine a least cost manure disposal strategy that complies with the *Code of Agricultural Practices for Waste Management* to avoid applying excessive amounts of nitrogen (N) on the land.

3. Use the information from the first two objectives to determine an optimum feeding and manure disposal strategy for an average poultry farm in the Fraser Valley.

The objectives above will be achieved by the use of linear programming models to determine the least cost diet for both the starter and grower rations, and the least cost manure disposal strategy.

1.4 Thesis Overview

This thesis consists of seven chapters. Chapter one presents an introduction to the problem of excess amounts of farm manures due to intensive agricultural practices and the effect of manure on water nitrate levels. Chapter two discusses the background of the poultry industry in British Columbia and the problems associated with the disposal of poultry manures. It also discusses the location and nitrate levels of the Abbotsford Aquifer. Chapter three discusses the literature pertaining to poultry nutrition and also to linear programming as a farm management tool. It also reviews general environmental regulations and laws governing the disposal of farm manures in British Columbia. Chapter four outlines the research methodology employed by this thesis. Chapter five discusses the data sources and the conversion of the data for use in the thesis. Chapter six presents the results and discussion of the thesis results. Chapter seven presents the conclusion and some recommendations.

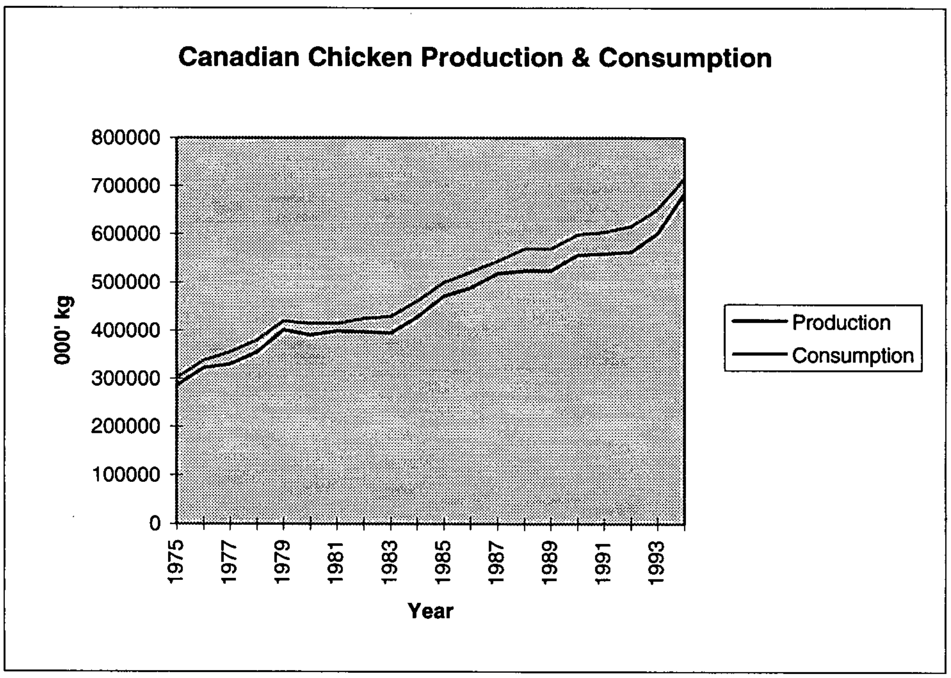
CHAPTER 2

BACKGROUND TO THE POULTRY INDUSTRY

2.1 Canadian Poultry Industry

The past twenty years show a significant rising trend in the amount of chicken produced and consumed in Canada as illustrated by figure 2.1 below.

Figure 2.1: Canadian Chicken Production and Consumption (1975-1994)[1]



Source: Agriculture and Agri-Food Canada, 1995

Between 1975 and 1994 chicken production in Canada increased by 140.7% rising from 284.6 tonnes in 1975 to 685.1 tonnes of meat in 1994. During this period, per capita consumption of chicken meat increased by 94.6% from 12.9 kg in 1975 to 25.1 kg in

[1] The difference between consumption and production is the change in stocks.

1994. This rising trend in chicken production and consumption was also observed in the US market where production increased by 195% and per capita consumption increased by 104.5% during the same time period (CCMA, 1995). Compared to other meats, per capita chicken consumption increased at a much faster rate whereas the consumption of some of the other meats decreased. Between 1975 and 1994, per capita consumption of pork increased by 11.4%, whereas that of beef and veal decreased by 32.6% and 43.5% respectively.

The Canadian broiler chicken industry has been under supply management since 1979. Supply management in this case refers to the use of quotas, import controls, and authority to set or negotiate prices in order to improve the stability of farm prices and farm incomes. The key instrument in supply management is quotas. The amount of chicken produced by each province in Canada is allocated by the Canadian Chicken Marketing Agency (CCMA) under the National Allocation and Pricing Agreement as quota to each province. This figure is reassessed every two years to account for new feeding programmes, new genetics/breeding which will affect relative positions such as feed and chick costs, cost of production, feed conversion, mortality, etc.

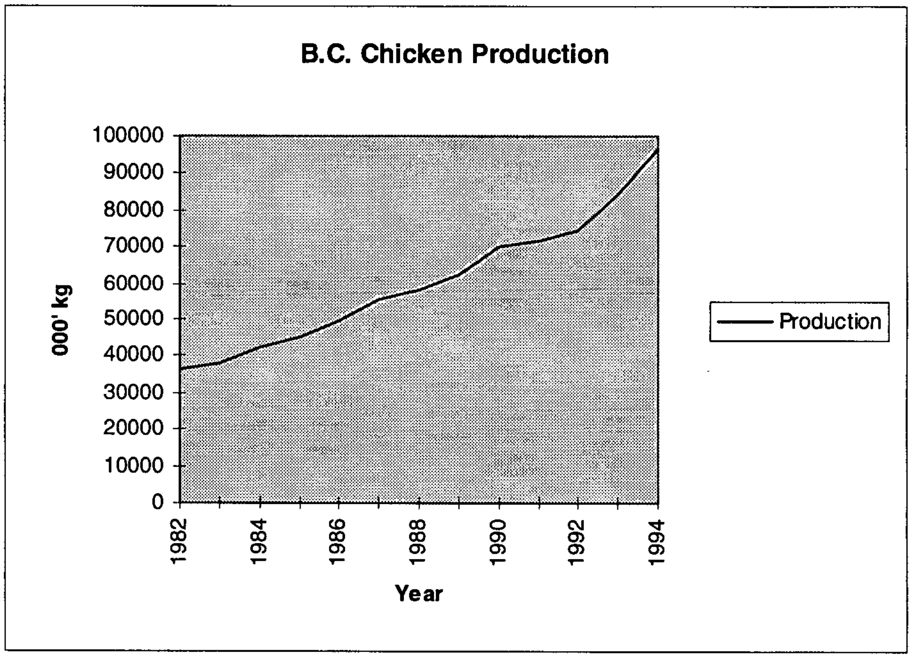
For supply management to succeed, the producers have to operate under marketing boards. Critics of this system have often charged that marketing boards exercise monopoly power to restrict supply and force prices higher resulting in an income transfer to producers (Veeman, 1982). Pricing is a provincial matter where the marketing agencies in each province establish a policy and method of calculating a cost of production

(C.O.P.). The average Canadian C.O.P. for 1991-1994 was 118.5 cents/kg of live weight and for British Columbia it was 119.9 cents/kg of live weight (CCMA, 1995).

2.2 British Columbia Poultry Industry

Poultry production in British Columbia consists of about 500 registered poultry producers and several thousand small unregistered ones and is an important industry in the province (Fullerton, 1990). Between 1982 and 1994 chicken production increased by 165.6% from 36,400 tonnes (eviscerated weight) in 1982 to 96,500 tonnes in 1994 as shown in figure 2.2. The largest increase occurred between 1992 and 1994. The farm cash receipts from poultry in 1994 were $153.2 million which accounted for 10.2% of total cash farm receipts in British Columbia. In Canada, BC Farm Cash Receipts are third in value after Ontario and Quebec (CCMA, 1994). In terms of birds produced, between the years 1981 and 1989 the number of broilers produced in BC increased by about 55% from 32.2 million to 50 million. The number of layers remained relatively stable at about 25 million (BC Chicken Industry Advisory Committee, 1991). The industry is especially important in the lower Fraser Valley where approximately 80% of the poultry production in British Columbia takes place.

Figure 2.2: BC Chicken Production (1982-1994)

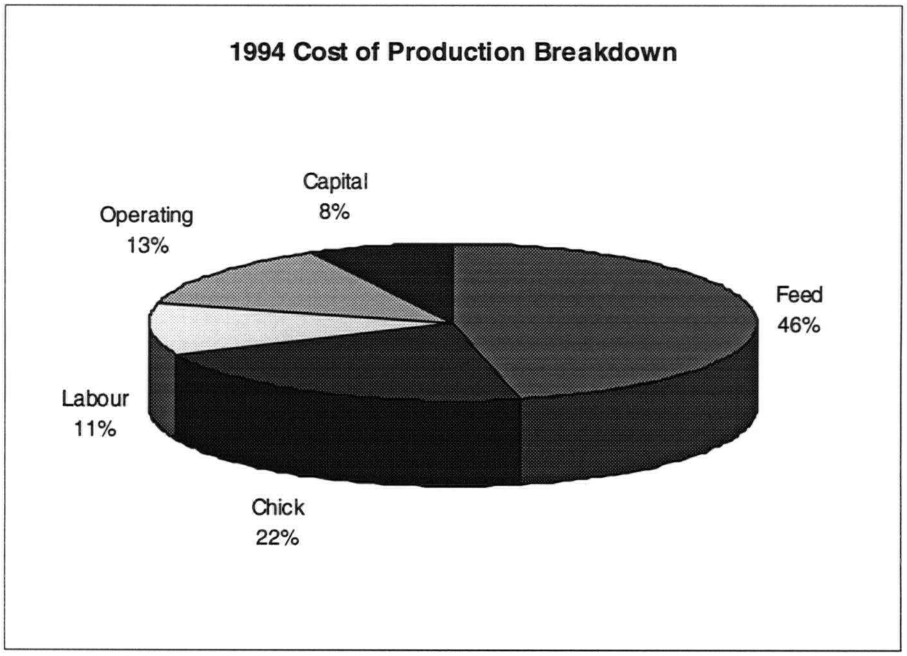


Source: Agriculture and Agri-Food Canada, 1995.

2.3 Poultry Diet

One of the most important components of the poultry industry and poultry production is the feed ingredients and diet. As shown below in figure 2.3, almost 50% of poultry production costs are due to the feed, therefore it is an important aspect to consider when one tries to make any changes in the production process. Some of the farms buy feed ingredients and mix their own rations while others prefer to buy rations that have already been formulated.

Figure 2.3: 1994 Cost of Chicken Production Breakdown



Source: Agriculture and Agri-Food Canada, 1995.

Poultry diets are composed of a mixture of various feedstuffs such as cereal grains, soybean meal, animal by-product meals, fats, and vitamin and mineral premixes. These feedstuffs contain proteins, amino acids, carbohydrates, fats, minerals, and vitamins that are essential for the bird's growth, reproduction, and health. The energy necessary for maintaining the bird's general metabolism and for producing meat and eggs is provided primarily by carbohydrates and fats. Dietary requirements for protein are actually requirements for the amino acids contained in the dietary protein. Amino acids perform a variety of functions in the body. As proteins, they are primary constituents of structural and protective tissues such as skin, feathers, bone matrix, and ligaments, as well as of the soft tissues, including organs and muscles (NRC, 1994). There are 22 amino acids in body proteins , and all are physiologically essential. Nutritionally, these amino acids can be divided into two categories: those that poultry cannot synthesize (essential) and those that can be synthesized from other amino acids (non-essential). The essential amino acids must be supplied by the diet and the non-essential ones that are not supplied by the diet are synthesized by poultry. The addition of amino acids in the diet may therefore lower the protein requirements thereby reducing nitrogen in the diet and manure. Total nitrogen is reduced because the added amino acids provide a more correct balance of amino acids with a minimum of excesses (NRC, 1994).

2.3.1 Other Dietary Considerations

Following are some dietary requirements that will not be varied in the experiments but nevertheless are important and will therefore be discussed briefly from the NRC (1994) manual.

(a) Energy

Energy is not a nutrient but a property of energy-yielding nutrients when they are oxidized during metabolism. The energy value of a feed ingredient can be expressed in several ways but the most common form used for poultry diets is, Apparent Metabolizable Energy (ME). This is the gross energy of the feed consumed minus the gross energy of the excreta (feces and urine). A correction for nitrogen retained in the body is usually applied to yield a nitrogen-corrected ME value (ME_n). Energy levels in poultry diets vary across regions but the common level in the Fraser Valley is 3200 kcal/kg.

(b) Carbohydrates

Dietary carbohydrates are important sources of energy for poultry. Cereal grains such as wheat, corn, and barley contribute most of the carbohydrates to poultry diets. The majority of carbohydrates from grains occur as starch, which is readily digested by poultry. There are other forms of carbohydrates such as cellulose and pentosans that are poorly digested or even impede the digestive process. The digestibility of these products can be improved by the addition of supplemental enzymes to the diet thereby improving nutrient utilization and growth. Improved nutrient utilization implies that less nutrients such as nitrogen and phosphorus are excreted in manure.

(c) Fats

Fat is usually added to the feed for meat-type poultry to increase overall energy concentration and, in turn, improve productivity and feed efficiency. Oxidation of fat is an efficient means to obtain energy for the cell in large quantities, whereas anabolic use involves direct incorporation into the body as a part of growth. In this experiment, fat was added as A/V supplement.

(d) Minerals and Vitamins

Minerals are the inorganic part of feeds or tissues. They are often divided into two categories (macro and micro), based on the amount that is required in the diet. Requirements for the macro-nutrients are reported in percentage of diet whereas requirements for the minor minerals are stated as milligrams per kilogram (mg/kg) of diet. Vitamins are generally classified under two headings: fat-soluble vitamins, A, D, E, and K, and water soluble vitamins, that include the B-complex and C (ascorbic acid).

Minerals and vitamins are usually added to the feed in the form of a premix. This means that all the required minerals or vitamins are combined and added as one component to the feed.

2.4 Poultry Manure Production and Disposal Options

In 1990, 45.4 million birds were produced in the Fraser Valley resulting in the production of 138,000 tonnes of manure of which 54% was produced in the Abbotsford/Matsqui area which lies above the Abbotsford aquifer (see Appendix I, figure 1). This amount of manure contains approximately 3,200 tonnes of Nitrogen as shown in table 2.1 below (SPFG, 1994). Approximately 50% of this manure was produced by broilers, and 20% by layers, and the remaining 30% by the rest of the poultry classes.

Table 2.1: Manure Production Estimates in the Fraser Valley (1990)

Zone	**Manure Production (tonnes)**	**Nitrogen Production (tonnes)**
Surrey/Langley West	23074	494
Langley East	15841	338
Aldergrove/Matsqui/Abbotsford	39741	1032
Abbotsford Airport	36597	894
Sumas Prairie West	10402	227
Sumas Prairie East	5491	144
Fraser River North	3696	56
Total	**134842**	**3185**

Source: SPFG, 1993.

Considering the cropland and crop nutrient requirements of this region, this amount of nitrogen is in excess of what can be used up locally. This amount of manure therefore poses concerns for water quality, soil degradation, and air pollution. The leaching problem is compounded further by the high rainfall of 1513 mm/year (Moon et al., 1994) and high water table prevalent in this region.

2.4.1 Manure Disposal Options

There are several methods available for manure disposal, and each one has different costs associated with it. Several of these methods will be discussed briefly and the ones that are more feasible at the farm level in the Fraser Valley will be discussed in more detail. In considering manure disposal it is important to note that the various housing systems used for poultry affect the costs of manure disposal and also the manure nutrient content. The housing system affects the moisture level of the manure which in turn affects the nutrient content level. Manures with high moisture content have higher handling costs and have a lower concentration of nutrients. The type of housing used will depend on the type of bird raised and the management goals of the farm. The housing system that is considered in this study is the solid litter system which is used for broilers (BCMAFF, 1992).

(a) Storage

After each cycle, manure is cleared out of the chicken house and sent off for disposal or is stored in a storage facility until it can be disposed of. It is therefore necessary to consider the storage requirements, costs, and leaching aspects of stored manure.

The *Code of Agricultural Practices for Waste Management* requires that storage structures be located a minimum of 15 m from any watercourse and a minimum of 30 m from wells or domestic water intakes. They should be located on a well drained area, properly graded to divert surface water away from the storage and be watertight. They should also be adequately fenced off to prevent accidental entry of humans, animals, or machinery and also be sized to provide storage that will enable the user to spread manure at the correct time of year to meet crop requirements. Although the ideal storage structure should have a concrete floor, concrete sides, and be covered, many farmers in the Fraser Valley do not have such structures. The three most common storage methods in the Fraser Valley are:

(i) uncovered and directly on the ground (65%),

(ii) a concrete floor slab without sidewalls (13%), and

(iii) a concrete floor slab with sidewalls (11%) (SPFG, 1994).

Covering of litter manure piles over the fall and winter period was found to reduce soil ammonium levels under a manure stockpile of about 100 cubic yards by about 2200 kg N/ha (or 79%) while the same practice reduced the total nitrate-N and ammonium-N levels by about 1900 kg N/ha (or 61%) (SPFG, 1994). The recommended manure storage capacity for all poultry operations is six months, therefore a 35,000 broilers/cycle operation which produces about 300 tonnes of litter per year should have a storage capacity of about 150 tonnes of litter. Calculations by Stennes (1992) indicate that variable manure storage costs are about $2.68/tonne/cycle and the total storage costs sum up to $21.43/tonne/cycle (Appendix I, Table 2).

(b) Land Application

Manure that is to be applied onto land is often stored through the winter months and then used in the spring as fertilizer for the crops. Spreading manure in the spring is recommended because that is the time when crops are planted and nutrient uptake is highest during the growth stage of the crops. During the summer months the manure does not have to be stored and can be applied onto the land immediately with crops that allow manure spreading while they are growing. All the plant available nitrogen is not taken up by crops since there are periods when the crop is not actively taking up nitrogen. There are therefore recommended rates of manure application for particular crops so that most of the nutrients are taken up. When manure is spread on the land, it should be incorporated into the soil within 24 hours so as to reduce the risk of runoff and the loss of ammonium nitrogen.

Most of the manure spread on the land in the Fraser Valley is used predominantly on raspberry fields. Poultry manure is widely used by raspberry producers as a source of nitrogen and as a soil amendment too. Raspberry and poultry farms are often located side by side and are sometimes owned by the same producer. This management practice serves as an example of good integration of different agricultural enterprises although there are some drawbacks because farmers tend to use more manure than the recommended rates since they often have a surplus of manure of which they need to dispose. In addition to manure, farmers also use inorganic nitrogen fertilizers. This high usage of fertilizers turns the fields into a potential source of nitrate leachate to the groundwater of the Abbotsford

Aquifer, with the highest potential occurring when inorganic fertilizers are used in conjunction with poultry manure to fertilize the raspberry crop. One recommendation to deal with this problem is to use poultry manure as a primary fertility source instead of inorganic fertilizers because there is less risk of nitrate leaching with manure than with inorganic fertilizers for the same amount of nitrogen. With appropriate manure and fertilizer nitrogen management, cover crops can be effective in reducing nitrate leaching over the fall and winter. Knowing past manure and crop management practices on the particular field is also important in deciding how much nitrogen to apply on the fields.

Considering labour costs and machinery costs, the actual variable costs of land application by a spreader as calculated by Stennes (1992) is $6.55/tonne and the total costs associated with spreading are $25.30/tonne (Appendix I, Table 2).

(c) Composting

Composting is a process that changes the form, handling characteristics, and potential uses of poultry manure to produce a commercial product that can be used for crop production, soil conditioning, and soil amendment purposes. Composting is an aerobic process which requires a combination of nutrients, water, and oxygen. The process is largely regulated by four factors: temperature, the carbon/nitrogen (C/N) ratio, moisture levels, and oxygen content. On a commercial basis, the two basic factors affecting financial success are the annual quantity of waste composted and the level of capital investment. Fullerton (1991) found compost production costs ranging from $47.35/tonne to $71.33/tonne of compost.

(d) Pelleting

Pelleting involves four basic processes: initial gathering and mixing of manure products, composting, pelletizing and final sales preparation (screening/sorting. weighing, and bagging). Manure pelleting systems and operations are normally designed for relatively large quantities of manure on a consistent basis. A certain amount of specialized equipment, management and marketing skill is required to achieve minimum production costs and develop a successful marketing system. Pelleting is a manure disposal option that may be feasible on a regional or semi-centralized basis.

(e) Energy Production (Biogas)

Anaerobic digestion is a biological process in which the waste is stabilized by bacteria in the absence of oxygen. Typical small-scale systems use the biogas that is produced to power electric generators. The net energy benefits of an anaerobic system include the electricity produced, plus the energy saved through the use of captured heat. Based on current energy prices and investment requirements, biogas production cannot be justified in the Fraser Valley.

(f) Transportation

Over the past twenty years a significant reduction in soil organic matter has been documented for Delta crop lands (SPFG, 1994). These intensively cultivated soils require amendments to maintain current cropping practices and yields in the future. One possible option that Delta vegetable farmers could use would be to transport the surplus manure from the Abbotsford/Matsqui area to Delta where there is a definite need for the manure. At the moment, this is happening on a very limited scale. A study carried out by Stennes (1992) found the cost of transporting manure to be \$0.179/tonne/km (density of 320 kg/m^3), therefore to transport manure from Abbotsford to Delta, a distance of about 60 km, it would cost \$10.74/tonne (Appendix I, Table 2).

In considering transportation, a farmer is faced with two choices. One of the options requires that after each cycle, the litter be removed from the barn and transported immediately to the vegetable farm. This option assumes that the vegetable farmer in Delta will store the manure until s/he can apply it onto the land, thereby facing the storage costs. In the second option the manure is stored on the poultry farm and then transported to the vegetable farm at the appropriate time when it can be applied on the vegetable crops. In this case, the poultry farmer will incur the storage costs. The SPFG (1994) report found storing manure at the crop farm is the most cost efficient because this requires less handling of the manure between storage and field application. Each handling operation of manure from storage to truck and vice versa costs \$8.10/tonne and the total costs associated with trucking are \$29.49/tonne (Stennes, 1992).

2.5 Abbotsford Aquifer

The current level of intensive poultry production and therefore high levels of manure production in the Fraser Valley presents a potential leaching problem for the Abbotsford aquifer which is the major source of water for human consumption and livestock production in this region.

2.5.1 Aquifer Location and Population it Serves

The Abbotsford aquifer is a large underground water source covering approximately 100 square kilometres in southwestern British Columbia and another 100 square kilometres in northwestern Washington (see Appendix I, Figure 1). The aquifer is an important source of groundwater for domestic, municipal, agricultural, and other industrial users in the region and provides almost all the water requirements for the residents of Abbotsford. The groundwater discharge feeds into the Nooksack River System (Atwater et al. 1994). Approximately 20% of the aquifer's surface is now covered by urban areas with the remainder being under intensive agriculture involving raspberry and livestock production. In portions of the area where raspberry production is more intensified such as the area located south of the airport, raspberry production comprises more than half of the total land use (Nelson, 1992). When combining soil and climate, this region provides the optimum environment for raspberry production. Almost 50% of all raspberries produced in North America come from southwest coastal B.C. (Daubney and Anderson, 1991).

Although poultry production makes up a small portion of the land usage area, the region is responsible for 57% of all manure produced from poultry sources in the Lower Fraser Valley, hence accounting for the greatest poultry producing region in the province. The most intensive poultry production comes from the airport region, which is also the most intensively farmed raspberry area. According to Chipperfield (1993) more than half of all manure produced from poultry sources is directly applied to raspberry crops.

2.5.2 Water Quality and Nitrate Accumulation

Liebscher et al. (1992) indicated that since 1955, over 450 groundwater samples analyzed for nitrates were collected from regional wells and piezometers which were initially on a large grid, but from 1984 sampling was closely examined in those sites which were most severely impacted. Kwong (1986) in Liebscher et al. (1992) investigated groundwater samples from the South Matsqui and South Abbotsford area region and found that 46 out of 73 (60%) sample sites had nitrate levels in excess of 10 mg/L, the maximum acceptable concentration set by Health and Welfare Canada in the Canadian Drinking Water Quality Guidelines with mean concentrations of 13.08 mg/L and maximum concentrations as high as 41.5 mg/L. The regions most severely affected were those surrounding the airport which incidentally is the area with the most intensive raspberry production, with five regions having in excess of 20 mg/L and three regions having an excess of 30 mg/L. Nitrate levels plotted over time suggest that there is a trend of progressively higher groundwater nitrate concentrations over time. (Liebscher et al. 1992).

Water quality on the unconfined aquifer can be attributed to the practices occurring on the land above the aquifer. Although, there are other sources of nitrates in the groundwater such as inorganic fertilizers, manure spreading is a major source. This region lies on a sensitive aquifer where the large macroporous regions of the sand and gravel geology of this area provide an ideal environment for the aerobic bacterial conversion of nitrogen into nitrates (Moon et. al., 1994).

It is therefore evident that the residents and farmers in the Fraser Valley should be concerned about manure management options because they may have a direct effect on water quality through the level of nitrates in the water.

CHAPTER 3

LITERATURE REVIEW

3.1 Background to Diet Experiments

Various solutions and strategies to reduce the problem of manure pollution have been considered from many different perspectives. Most of the suggested solutions consider the mitigation of manure pollution after the manure has been produced, but few have been considered that look at the problem before the manure is produced e.g. by modifying the diet of the chicken. Some of the work that has been done in this field and several of the strategies and findings are mentioned below.

This chapter also discusses some background to the theory and practice of linear programming, gives some background to the economic theories and principles relating to environmental (manure) pollution, and outlines British Columbia's policies dealing with farm pollution problems.

Dr. R. Blair and Dr. J. Jacobs of the Department of Animal Science at UBC designed and carried out several experiments on broilers to determine the effects of varying the levels of protein and amino acids in the diet. These experiments demonstrate the effects of feeding different levels of dietary protein with varying levels of amino acids in the diet. Specifically, the experiments considered consisted of 8 dietary treatments with varying protein levels ranging from a high of 25% CP (crude protein) to a low of 18% CP as shown below in table 3.1. At each protein level, amino acids were included at the standard level (NRC, 1994), at 10% higher than the standard level, and at 10% lower than the standard level. The same balance of amino acids was maintained at each of these levels.

Table 3.1: Dietary Treatments

Dietary Treatment	Starter Ration		Grower Ration	
	Crude Protein (CP)	Amino Acids (AA)	Crude Protein (CP)	Amino Acids (AA)
1	25%	control	21%	control
2	21%	+10%	18%	+10%
3	21%	control	18%	control
4	21%	-10%	18%	-10%
5	25%	control	18%	control
6	21%	+10%	21%	control
7	21%	control	21%	control
8	21%	-10%	21%	control

Source: Blair and Jacobs

The data collected included weight gain, feed efficiency, litter moisture content, and manure excretion. The manure samples were then chemically analyzed for nitrogen. The following section is a discussion and literature review by Drs. Blair and Jacobs which gives some background to the poultry diet experiments. This section is quoted from the experimental draft protocol.

> Currently feedstuffs are combined to meet the bird's needs for the most limiting amino acids. This usually results in a higher than required protein (nitrogen) content of the diet due to the presence other amino acids in excess. Using synthetic amino acids diets can be formulated which meet the bird's amino acid requirements but with a reduced total protein content. This provides the appropriate levels of essential amino acids while avoiding large excesses, and is a sound approach to minimizing nitrogen input and utilizing the dietary nitrogen most efficiently. More accurate information is now available on the amino acid content of feedstuffs and the commercial availability of new synthetic amino acid feed supplements suggests that we

should make optimal use of these supplements to minimize nitrogen excretion in animals. Methionine and lysine have been available commercially for some time, and threonine and tryptophan are now available. It is highly likely that other synthetic amino acids will soon become available and economical for commercial use in feeds. The use of synthetic amino acids in dietary supplements allows the total dietary nitrogen to be reduced, while meeting the bird's needs for amino acids. This can reduce nitrogen excretion in swine manure by 29% (Coffey, 1992). Similar estimates for laying hens range from 20% (Blair et al, 1976) to 50% (Klasing, 1993), and for broilers from 10% (Han et al., 1992) to 30% (Parr and Summers, 1991).

Some recent work has demonstrated that equivalent growth performance can be obtained in 7 to 21 day-old broilers fed diets containing the standard levels of protein or reduced protein diets supplemented with amino acids (Parr and Summers, 1991; Han et al., 1992). Total carcass protein of birds fed the reduced-protein diets in which all essential amino acids were minimized was equal to that of the control birds, confirming that the efficiency of protein utilization of birds fed correctly-balanced, reduced-protein diets is superior to that of birds fed a standard protein diet. Carcass composition was studied in these investigations since it is well known that percentage carcass protein decreases and percentage carcass fat increases when the energy:protein ratio in the diet is widened, possibly through an effect of energy level on feed intake. The results of Parr and Summers (1991) showed that feed intake was similar in birds given diets differing by 15% in energy concentration when they contained equal concentrations of essential amino acids. This suggests that feed intake is highly influenced by a requirement for intake of essential amino acids, further suggesting that increased carcass fatness can be avoided in broilers fed reduced protein diets provided the dietary level of essential amino acids is adequate.

The overall conclusion that can be drawn from the research cited above is that similar growth performance and body composition of broilers can be maintained on reduced-protein diets as on conventional diets. However, it is necessary to have accurate information on the amino acid composition of the dietary constituents, and supplements of the limiting amino acids must be added. The use of reduced protein diets allows the total nitrogen content of the diet to be reduced by at least 10% and possibly 20-25%.

3.2 Linear Programming

Linear programming is one of a class of operations research methods referred to as mathematical programming. It was developed in the 1940s for use in military operations, but was subsequently found well suited to solving a range of business and commercial planning problems. Today it's one of the most used operations research techniques, and in agriculture it has been used extensively in farm enterprise selection, in transportation (determination of optimal routing) and in the selection of least cost feed mixtures for livestock.

The first use of linear programming in diet formulation was in 1945 when George Stigler published a controversial paper in the *Journal of Farm Economics* entitled, "The Cost of Subsistence". He wanted to find the minimum cost of diet for a moderately active man (this was in response to the shortages of various foodstuffs during the Second World War). Against this background, Stigler formulated one of the first linear programming problems demonstrating the feasibility and the economic meaning of the notion of an adequate diet (Paris, 1990). But it was not until 1947 when G.B. Dantzig, L. Hurwicz, and T.C. Koopmans discovered a computational procedure (the simplex algorithm) for general linear programming problems that these problems were able to be solved. Today, these problems require the use of a computer because of the very large number of calculations that have to be performed.

The linear programming technique is a general methodology that can be applied to a wide range of problems that have the following characteristics:

(i) a range of activities are possible and the farmer can exercise a choice in the selection of activities the s/he wishes to put into operation,

(ii) various constraints prevent free selection from the range of activities, and

(iii) a rational choice of a combination of activity levels is related to some measure of the farmer's utility (for example, profit) associated with each of the activities, that is, an objective which can be quantified.

Linear programming has been used a good deal as a farm planning technique generating valuable information to aid planning decisions of many farms. Despite these applications, linear programming has not been used by a significant number of farmers as a routine planning aid. Given the potential for the technique, it is appropriate to ask what have been the obstacles to its wider adoption. Dent et al. (1986) lists some of the factors limiting it's adoption:

(i) doubts as to the appropriateness of the technique to real farm planning

(ii) improper use of the technique

(iii) unavailability of adequate data for planning purposes

(iv) high cost of applications

(v) unavailability of suitable computing facilities

(vi) scarcity of personnel skilled in carrying out a linear programming analysis

(vii) lack of awareness by farmers of the potential of the technique

The recent availability of affordable computers has done much to dispel many of these largely psychological barriers. In the past, there has been a tendency to interpret results too literally and place too much emphasis on the acceptance of a single optimal plan (Dent et al, 1986). Linear programming should be used as a support for decision making in which the results of several computer optimization runs are used to generate a substantial amount of information which the farmer can integrate with her/his existing knowledge.

In its simplest form, linear programming is a method of optimizing a combination of farm activities that are feasible with respect to a set of fixed farm constraints. In this analysis, the optimization case being considered is feed cost minimization and the minimization of manure disposal costs.

3.3 Review of Environmental Regulations

A brief review of environmental economics is helpful in understanding the manure/nitrogen pollution problem. The following concepts are important to consider when drawing up solutions to the manure pollution problem.

3.3.1 Externality

Environmental economics utilizes the theory of externalities to measure environmental standards (in this case water quality). Externalities can be significant factors in both production and consumption activities and they arise because the externality-producing firm imposes damages or costs on others that it does not consider in its profit-maximizing decisions, in this case this would be a farmer producing excessive amounts of manure and applying it on the land thereby resulting in water pollution. Regulation of agricultural technology to internalize externalities can be expected to increase costs as higher cost inputs are substituted, or lead to reduced output when such substitutes are not available. The extent to which productivity is affected depends upon opportunities for input substitution, possibilities for “abatement” technology and the specific regulatory mechanism employed. The lower protein diet in this case could be considered as a new or “abatement” technology intended to internalize the externality and the transportation of manure would be considered as a substitution intended to internalize the externality. When no abatement possibilities exist and the externality being generated is proportional to the agricultural output produced, production will fall if producers are made to internalize the externalities. In the long run, the effects on productivity may be traced through the changes in profitability (Capalbo and Antle, 1988). If profit declines as a result of the regulations, adjustments in production patterns and factor use can be expected. Requiring a farmer to dispose of the manure in an environmentally responsible manner is a way of internalizing the externality because it increases the overall cost to the farmer. The farmer will therefore choose the least expensive “abatement” technology that meets the environmental regulations.

3.3.2 Types of Regulations

There are generally two principal approaches to pollution control and waste management:

(a) command-and-control,

(b) economic strategies.

(a) Command and Control

The command-and-control approach gives the regulator maximum authority to control where and how resources will be spent to achieve environmental objectives. It also generally requires a government to set health or ecology based ambient environmental objectives and specify the standards or amount of pollutants that can be discharged or the technology by which polluters should meet those objectives. This is the case in British Columbia where the water quality level is set by the federal government at a maximum of 10 mg/L of nitrate-nitrogen in drinking water. The government also has regulations on how manure should be stored and when and where is should be disposed of. This method is often used by government agencies to control pollution and waste management. The approach relies primarily on regulatory instruments such as ambient environmental quality standards, effluent emission standards, product and process standards, permits and licenses, land and water use controls, etc.

(b) Economic Strategies

Economic strategies use the polluter-pays and user-pays principles. According to the polluter-pays principle, the polluter pays a financial penalty for higher levels of pollution and pays a smaller penalty or receives a financial reward for lower levels of pollution. This would be the case if a farmer in British Columbia got a subsidized loan from the ALDA (Agricultural Land Development Assistance) to construct a structure that would reduce pollution. According to the user-pays principle, the user of a resource pays the full social cost of supplying the resource. This approach usually incorporates regulatory instruments as well as the following economic instruments: effluent and emission charges, user charges, product charges, administrative charges, tax differentiation, marketable permits, subsidies, non-compliance fees, etc.

3.4 Environmental Regulations in B.C.

British Columbia employs a combination of the two approaches discussed above with a greater weight towards command-and-control. Policies such as "maximum allowable" nitrate levels in drinking water, location of storage structure with respect to the water source, period of manure application, etc. are all examples of command and control. Economic strategies are difficult to regulate in the case of environmental pollution since they require sophisticated institutions to implement them such as marketable permits and effluent or emission charges. This is also difficult to enforce in the case of a non-point source such as manure pollution.

British Columbia regulations regarding the handling of farm wastes are outlined in the *Code of Agricultural Practices for Waste Management* under the *Waste Management Act.* This act contains guidelines on how and where manure should be stored, and the periods of time when it can be applied to the land and basically states that agricultural waste must be handled in a way that does not impact on the environment. The code is rather vague in several aspects but is explicit in the two following important points, it states that:

(i) agricultural waste may be stored on a farm only if the waste is produced or used on that farm and also that the storage facility must be located at least 15m from any watercourse and 30m from any source of water for domestic purposes.

(ii) in regions that have greater than 600 mm of rainfall during the months of October to April inclusive, field stored agricultural waste must be covered during these months to prevent the escape of wastes that causes pollution.

These restrictions are binding to poultry producers in the Fraser Valley where many farms do not have enough land to store manure on and may therefore transfer it to another farm and the precipitation during the months of October to April is also rather high at 1100 mm (Moon et al., 1994).

Beginning in 1995, the Ministry of Environment Lands and Parks (M.E.L.P.) started enforcing a "compliance strategy". The long term goal of this strategy is to protect the environment and ensure that agriculture is not contributing to excess degradation of ground and surface waters. The two aspects that are targeted are:

(i) fall and winter spreading of manure on bare ground

(ii) field storage of solid manure.

Monitoring of these activities will be identified by aerial and ground surveillance, and through complaints received. Producers who are found not to comply with the regulations above will be subject to charges under the *Waste Management Act.*

The B.C. Ministry of Agriculture, Fisheries, and Food has additional non-regulatory programs regarding waste management which are briefly outlined below:

1. Best Agricultural Waste Management Plans

This program provides waste management recommendations to poultry producers who have pollution concerns caused by manure collection, storage, or spreading, disposal of dead birds, poultry feed, and yard runoff.

2. Best Soil Management Plans

This program is intended to provide soil management recommendations for farms that have problems with soil erosion, soil compaction, organic soil subsidence, soil structure deterioration, soil moisture deficit, or soil acidity. There is an important relationship between soils, manure, and nutrients and any information on the soil will be helpful to the farmer in making manure management decisions.

3. Nitrogen Behaviour Simulation Computer Model

The model simulates nitrogen behaviour from the time it leaves the animal as manure until it enters the soil and is eventually taken up by a crop, lost to the environment or becomes a component of soil organic matter. The model consists of four parts: manure transformations during collection, storage and spreading, soil processes, crop growth, and water movement through the soil. This model can be used to assess manure management practices to determine effect on crop production and the potential for environmental contamination.

4. The ALDA Program

The ALDA (Agricultural Land Development Assistance) Program provides low interest loans for on-farm capital improvements. Agricultural credit is available for a minimum project cost of $5,000 to a maximum loan of $75,000 per farm operation. Loans are on a 15 year term and interest rates are at half of the bank prime rate on approved credit. This program covers loans for environmental initiatives and adoption of new technologies such as the construction of a manure storage facility.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Average Poultry Farm in the Fraser Valley

A computer model was developed to find the lowest combined cost for feed and litter disposal for the eight experimental dietary treatments. The model first finds the least cost diet for each of the eight dietary treatments. The results from the least cost diet are then combined with data from a typical poultry farm in the Fraser Valley to calculate the feed costs on an annual basis for each dietary treatment. Next, a model of litter disposal is developed to find the minimum annual litter disposal cost under various scenarios of land availability and ability to transport litter. Finally, the least cost strategy for the combined feed and litter disposal strategy is found.

In carrying out this analysis, an average poultry farm in the Fraser Valley was considered. According to the SPFG (1994) report, the average poultry farm raises 35,000 birds (broilers) per cycle and has six cycles per year, thereby producing 210,000 birds per year. Each production cycle consists of six weeks (42 days) with a few days in between cycles for cleaning out the barn and getting in a new stock of chicks. The farm has some land for growing crops with the most common crops in this area being fertilized grass and raspberries. The average cropland available on a poultry farm in the Fraser Valley is 7.7 ha (19 acres) for the larger farms, and 4.9 ha (12 acres) for the smaller farms (SPFG, 94). It is also assumed that half the cropland is used for growing fertilized grass and the other half is used for growing raspberries.

The following sections describe each stage of building the economic model. The data used for the following stages is presented in detail in chapter 5.

4.2 General Linear Programming Model

For a given farm situation, the linear programming model requires specifications of the following points:

(i) the alternative farm activities, their unit of measurement, their resource requirements, and any specific constraints on their production,

(ii) the fixed resource constraints of the farm, and

(iii) an objective that can be quantified (in this case, cost minimization).

To formulate the problem mathematically we introduce the following notation:

X_j = The level of the j^{th} farm activity.

Let n denote the number of possible activities: $\Rightarrow$ then j = 1 to n

c_j = The cost of a unit of the j^{th} activity

a_{ij} = The quantity of the i^{th} resource required to produce one unit of the j^{th} activity.

Let m denote the number of resources: $\Rightarrow$ then i = 1 to m

b_i = The minimum amount of the i^{th} resource required.

With this notation, the linear programming model can be written as follows:

$$\textbf{min } Z = \sum_{j=1}^{n} c_j X_j \qquad (4.1)$$

such that:

$$\sum_{j=1}^{n} a_{ij}X_j \geq b_i \qquad i = 1 \text{ to } m \qquad (4.2)$$

and

$$X_j \geq 0 \qquad j = 1 \text{ to } n \qquad (4.3)$$

In words, the problem is to find the plan (defined by a set of activity levels X_j, j = 1 to n) that minimizes Z (equation 4.1), but which does not violate any of the fixed resource constraints (equation 4.2) or involve any negative activity levels (equation 4.3). This problem is known as the primal linear programming problem in this case.

The problem above can be portrayed in matrix form or tableau form (convention terminology) showing all the coefficients of the algebraic statements of the model. First, the equation to be minimized is called the objective function. In the current problem, the objective function is to minimize costs. Second, the constraints are called rows and the activities are called columns. Third, the fixed resource supplies, the b_i coefficients are called the right-hand side or RHS, of the problem. They are stipulated by ≥ , ≤, or =.

The nonnegativity requirements (equation 4.3) are not included in the tableau. By convention they are taken for granted in linear programming (Hazel, 1986).

Table 4.1: General LP Tableau

	Activity	Columns			
Row name	X_1	X_2	....	X_n	**RHS**
Objective function	c_1	c_2	...	c_n	**Min**
Resource constraints			...		
1	a_{11}	a_{12}	...	a_{1n}	$\geq b_1$
2	a_{21}	a_{22}	...	a_{2n}	$\geq b_2$
...	...	...	...	...	...
m	a_{m1}	a_{m2}		a_{mn}	$\geq b_m$

Source: Hazel, (1986)

4.3 Stage 1: Linear Programming Model for Least Cost Diet

In minimizing feed costs, a variety of feedstuffs and feed additives are used to attain the diet requirements at the least cost. The feedstuffs considered here are the common ones used in the Fraser Valley and these include corn, wheat, soybean meal, and meat meal. Some of the other feed additives used are limestone, di-calcium phosphate, A/V fat, mineral premixes, coccidiostats, and medication. There is also the addition of commercial amino acids such as lysine (L-LYS), methionine (DL-MET), threonine (L-THR) and tryptophan (L-TRY). All these ingredients (activities) are denoted by X_j in the mathematical representation.

The levels of crude protein (CP), metabolizable energy (ME), amino acids, and minerals in the feedstuffs are obtained from the National Research Council (NRC, 1994) standards. These values are denoted by a_{ij} in the mathematical representation. The dietary requirements for amino acids, minerals, and metabolizable energy (ME) are also obtained from the NRC (1994) standards for the starter and grower rations. These dietary requirements are denoted by b_i in the mathematical representation. Some of the feedstuffs such as corn, wheat, soybean meal, and meat meal have an upper and lower level in the diet. This is necessary in order to create a feed that is palatable. The upper and lower limit levels for these feedstuffs were obtained from Leeson and Summers (1990).

4.3.1 Least Cost Diet Tableau

A linear programming model was constructed to determine the least cost diet for each dietary treatment. The model solves for the minimum cost of one tonne of the starter ration and one tonne of the grower ration. The choice to use one tonne of feed is determined by the fact that feed prices in the poultry industry are quoted in terms of price per tonne ($/tonne). The model is solved using Excel spreadsheet model building capabilities and has the following key features.

(i) minimize total cost of fixed feed amount (one tonne of starter ration and one tonne of grower ration)

(ii) separate starter and grower rations

(iii) feed conversion data obtained from research data

(iv) feed ingredients and feed supplement prices obtained from suppliers

X_j = feeding activities (e.g. corn, wheat, L-LYS, etc.)

c_j = unit cost of each feeding activity ($/kg)

a_{ij} = nutrient levels in each unit of the feeding activities (e.g. % nitrogen, % lysine, etc.)

b_i = minimum nutrient requirements for the diet (these vary according to the dietary treatment in question)

The resource constraints are divided into two groups for the starter phase (i = 1 to 24) and the grower phase (i = 25 to 48) as shown below in table 4.2. A list of all the activities is given below in table 4.3 and is also divided into two groups to represent the starter phase (X_1 to X_{14}) and the grower phase (X_{15} to X_{28}).

Table 4.2: Feed Resource Constraints

	Resource Constraint		**Resource Constraint**
i	***Starter Phase***	*i*	***Grower Phase***
1	Metabolizable Energy (cal/kg)	25	Metabolizable Energy (cal/kg)
2	Crude Protein (%)	26	Crude Protein (%)
3	Lysine (%)	27	Lysine (%)
4	Methionine (%)	28	Methionine (%)
5	Methionine and Cystine (%)	29	Methionine and Cystine (%)
6	Threonine (%)	30	Threonine (%)
7	Tryptophan (%)	31	Tryptophan (%)
8	Available Phosphorus (%)	32	Available Phosphorus (%)
9	Total Phosphorus (%)	33	Total Phosphorus (%)
10	Calcium (%)	34	Calcium (%)
11	Crude Fibre (%)	35	Crude Fibre (%)
12	Crude Fat (%)	36	Crude Fat (%)
13	Medication and Coccidiostat	37	Medication and Coccidiostat
14	Trace Mineral and Vitamin Premix	38	Trace Mineral and Vitamin Premix
15	Corn Upper Limit	39	Corn Upper Limit
16	Corn Lower Limit	40	Corn Lower Limit
17	Wheat Upper Limit	41	Wheat Upper Limit
18	Wheat Lower Limit	42	Wheat Lower Limit
19	Soybean Meal Upper Limit	43	Soybean Meal Upper Limit
20	Soybean Meal Lower Limit	44	Soybean Meal Lower Limit
21	Meat Meal Upper Limit	45	Meat Meal Upper Limit
22	Meat Meal Lower Limit	46	Meat Meal Lower Limit
23	Starter Feed	47	Grower Feed
24	Starter Feed Limit (kg)	48	Grower Feed Limit (kg)

Table 4.3: Feed Activities

	Feeding Activity		Feeding Activity
X_j	***Starter Phase***	X_j	***Grower Phase***
X_1	Corn	X_{15}	Corn
X_2	Wheat	X_{16}	Wheat
X_3	Soybean Meal	X_{17}	Soybean Meal
X_4	Meat Meal	X_{18}	Meat Meal
X_5	Limestone	X_{19}	Limestone
X_6	Dicalcium Phosphate	X_{20}	Dicalcium Phosphate
X_7	L-Lysine	X_{21}	L-Lysine
X_8	DL-Methionine	X_{22}	DL-Methionine
X_9	L-Threonine	X_{23}	L-Threonine
X_{10}	L-Tryptophan	X_{24}	L-Tryptophan
X_{11}	A/V Fat	X_{25}	A/V Fat
X_{12}	Medication and Coccidiostat	X_{26}	Medication and Coccidiostat
X_{13}	Trace Mineral and Vitamin Premix	X_{27}	Trace Mineral and Vitamin Premix
X_{14}	Starter Feed	X_{28}	Grower Feed

A least cost diet tableau for one of the dietary treatments is shown in appendix II, Table 1. It is sufficient to look at one of the dietary treatment tableaux to follow the least cost mechanism described below. The tableau is divided into two major sections to account for the starter phase (0-3 weeks) and the grower phase (3-6 weeks). The starter ration component is represented by rows 3-26 and the grower ration is represented by rows 27-50.

Row 1 represents the objective function (also known as the changing row) and gives the weight of each feed ingredient at the optimum (least cost) solution.

$$\min Z = \sum_{j=1}^{n} c_j X_j \qquad (4.4)$$

Row 2 represents the unit costs of all the feed ingredients ($/kg).

Starter Phase

Rows 3-16 represent the diet requirements for the starter phase.

$$\sum_{j=1}^{n} \mathbf{a_{ij}X_j \geq b_i} \qquad i = 1\text{-}14 \qquad (4.5)$$

Rows 17-24 represent the upper and lower limits of some of the feed ingredients (expressed as a percentage of the diet) for the starter phase.

$$\sum_{j=1}^{n} \mathbf{\geq, \leq, \text{or} = b_i} \qquad i = 15\text{-}22 \qquad (4.6)$$

Rows 25 and 26 ensure that the starter ration formulation sums up to one tonne.

$$\sum_{j=1}^{n} \mathbf{a_{ij}X_j = 1000kg} \qquad i = 24 \qquad (4.7)$$

Grower Phase

Rows 27-40 represent the diet requirements for the grower phase.

$$\sum_{j=1}^{n} \mathbf{a_{ij}X_j \geq b_i} \qquad i = 25\text{-}38 \qquad (4.8)$$

Rows 41-48 represent the upper and lower limits of some of the feed ingredients (expressed as a percentage of the diet) for the grower phase.

$$\sum_{j=1}^{n} \mathbf{a_{ij}X_j \geq, \leq, \text{or} = b_i} \qquad i = 39\text{-}46 \qquad (4.9)$$

Rows 49 and 50 ensure that the grower ration formulation sums up to one tonne.

$$\sum_{j=1}^{n} \mathbf{a_{ij}X_j = 1000kg} \qquad i = 48 \qquad (4.10)$$

4.4 Stage 2: Converting Least Cost Diet Results to Farm Feed Costs

The results from the linear programming model in stage 1 provide least cost diet formulations for the starter and grower rations. They also provide the price per tonne for each of the starter rations and grower rations. These results are presented in appendix III, tables 1 to 8. These results are then converted to actual consumption of feed and feed costs per cycle and per year for a typical Fraser Valley farm.

The amount of feed consumed is obtained from the research data by Blair and Jacob for feed consumed by each bird for the starter phase and the grower phase. This number is then multiplied by the number of birds on the farm to get the total amount of feed consumed per cycle and then per year.

In order to simplify the analysis, an aggregate feed price for both the starter and grower rations was calculated as shown below. The least cost price for the starter ration and grower ration obtained from stage 1 is used to derive this aggregate feed price for each dietary treatment. This aggregate price takes into consideration the price of the starter and grower rations weighted by the amounts of feed consumed by the birds in each of the respective phases and its derivation is shown below.

$P_A = (P_s * F_s + P_G * F_G)/ F_T$

P_A = *Aggregate Feed Price*

P_s = *Price of starter ration (\$/kg)*

F_s = *Amount of feed consumed in starter phase (kg)*

P_G = *Price of grower ration (\$/kg)*

F_G = *Amount of feed consumed in grower phase (kg)*

F_T = *Total amount of feed consumed over the whole growth cycle of 6 weeks (kg)*

4.5 Stage 3: Selected Litter Disposal Options

Section 2.4.1 lists several litter disposal options and their associated costs. The options considered for this analysis are those that are feasible/affordable to an individual farmer in the Fraser Valley and the more costly ones are therefore omitted.

The option of composting would be economically feasible only if it had a market value of at least \$47.35 per tonne[2]. The current price of compost in the Fraser Valley is way below this value. This option will therefore be omitted. Construction of a pelleting facility can only be economical on a regional basis and no individual farmer can afford it. This option will also be omitted. The production of biogas is not very expensive but based on current energy prices in B.C., it is not reasonable to produce biogas for energy purposes. This option is common in areas where energy prices are very high or where accessibility to energy is difficult (such as in developing countries). This option will also be omitted. The model is therefore set up so that the litter produced in each period is disposed of by one or a combination of the following options:

(i) Storage

(ii) Spreading on land

(iii) Transportation

[2] \$47.35 is the production cost for one tonne of compost (Fullerton, 1991). In order for the production of compost to be economically feasible, the price should at least cover the production costs.

4.5.1 Linear Programming Model for Litter Disposal

In constructing the linear programming model the three options listed above are the ones that were considered. It is assumed that after the litter is cleared out of the barn it is either stored in a storage structure, spread on the land as fertilizer, or transported off the farm. The model covers a period of one year and is divided into six periods of two months each to depict the six production cycles for poultry production. Since the recommended storage capacity for litter is six months, we assume that the farm has the storage capacity for 150 tonnes of litter. The amount of litter spread on the land is dependent on the land base available for spreading and the type of crop being grown, as discussed in section 2.4.1.2. In complying with B.C. environmental regulations, the litter can be spread on the land only in spring and fall. Two options were considered when transporting litter off the farm:

(i) The poultry farmer can transport the litter to the vegetable farm throughout the year

(ii) The farmer is limited to transporting the litter only in the spring and fall, during the periods when the vegetable farmers can spread the litter.

In scenario two the poultry farmer incurs most of the litter storage costs. The following four scenarios are therefore considered in litter disposal:

1a. 7.7 ha of land and year round transportation

1b. 7.7 ha of land and transportation in the spring and fall only

2a. 4.9 ha of land and year round transportation

2b. 4.9 ha of land and transportation in the spring and fall only

During periods when the litter cannot be spread on the land or transported off farm, the litter is stored. A transfer row for stored litter is therefore included to account for the storage cost in each period. In other words, if litter that is produced during the Dec-Jan period has to be stored until the Apr-May period, then the transfer row will ensure that the storage costs for this litter is accounted for throughout the storage period.

All the activities listed above are expressed in terms of litter production but the research data is given in terms of nitrogen production, therefore the amount of nitrogen produced will have to be converted to its equivalent in terms of litter. The conversion process is shown in section 5.2.

Litter Disposal Model

Litter Disposal Activities

The model consists of three activities that are repeated for each of the six periods in the model, therefore, there is a total of 18 activities over the whole year. The three activities are listed below and are represented by Y_j.

Y_j	Activities
Y_1	Litter Storage
Y_2	Land Application
Y_3	Transportation

Litter Disposal Periods

The model covers one year and consists of six periods of two months each. The periods are listed below and are represented by k.

k	Period
k = 1	Dec-Jan
k = 2	Feb-Mar
k = 3	Apr-May
k = 4	Jun Jul
k = 5	Aug-Sep
k = 6	Oct-Nov

Litter Disposal Resource Constraints

The model consists of four constraints that are repeated for each of the six periods in the model, therefore there are 24 constraints for the whole year. The constraints are listed below and are represented by β_i.

β_i	Constraint
β_1	Litter Disposal or Production
β_2	Storage Limit
β_3	Land Application Limit
β_4	Transportation Limit

The coefficients (a's) in standard linear programming models for each activity equal one because the data has been transformed outside the model. The constraint limits are accounted for in the RHS variables in terms of litter. Since all the coefficients (a's) are equal to one they will not be shown in the equations. The litter disposal model is represented mathematically by the following equations.

Objective Function

Equation 4.11 represents the objective function. This function minimizes the litter disposal costs over the whole year. The cost for a particular a activity (c_j) is the same regardless of the period. For example, the cost for litter storage in period 1 is the same as in periods 2, 3, 4, etc.

$$\min Z_L = \sum_{j=1}^{n} \sum_{k=1}^{p} c_j Y_{jk} \qquad n = 3 \qquad (4.11)$$

$$p = 6$$

Litter Disposal or Litter Production Constraint (β_1)

Equation 4.12 represents the litter disposal or litter production constraint. This constraint ensures that the amount of litter disposed in each period is less than or equal to the amount of litter produced in that particular period. The litter is disposed of by one of the three activities listed above (Y_j), either by storage, land application, or transportation off farm. The amount of litter produced in each period is known outside of the model and is constant for each particular dietary treatment. Given that this is a minimization problem, A $\geq$ sign is used instead of a $\leq$ sign in equation 2 below. This means that the model will utilize the minimum amount of litter allowed by the constraint in order to minimize costs.

$$\sum_{j=1}^{n} Y_{jk} \geq \beta_{1k} \qquad n = 3 \qquad (4.12)$$

$$\text{for } k = 1 \ldots 6$$

Litter Storage Constraint (β_2)

Equation 4.13 represent the litter storage constraint. It ensures that the amount of litter stored in each period is less than 150 tonnes (the assumed storage capacity). During the last period (k = 6), all the litter has to be moved out of storage, therefore, the storage in period 6 is 0.

$\mathbf{Y_{1k} \leq \beta_{2k}}$ for k = 1 (4.13)

$\mathbf{Y_{1k} + T_{k-1} \leq \beta_{2k}}$ for k = 2...6 (4.14)

β_{2k} = 150 for k = 1...5, β_{2k} = 0 for k = 6

T_k = Manure stored in period k

Land Application Constraint (β_3)

Equation 4.15 represents the land application constraint. This constraint ensures that the amount of litter spread on the land in each period is not greater than the recommended amount. The recommended amount of litter spreading is calculated outside the model and is determined by the capacity of the available land to use up the nitrogen in the litter. This constraint is reflected in the RHS variable.

$\mathbf{Y_{2k} \leq \beta_{3k}}$ for k = 1...6 (4.15)

Transportation Constraint (β_4)

Equation 4.16 below represents the transportation constraint. This constraint regulates the times of year when litter may or may not be transported. The value for β_4 is set very high so as not to be binding during times when the litter can be transported since it is assumed that litter transportation is not limited during these periods. But this value is set at zero during times of the year when litter cannot be transported.

$\mathbf{Y_{3k} \leq \beta_{4k}}$ for k = 1...6 (4.16)

A sample tableau for litter disposal is shown in appendix II, Table 2. The tableau has six sections to represent the six production cycles per year. An annual feeding activity is included in the tableau to show the feed costs. This provides a result that includes the combined costs of feed and litter disposal. A transfer row is also included in the tableau to account for storage costs for litter that is stored over several periods. Since the annual feeding activity is already known from stage 2, it is included in this model only once as an annual feed cost activity and not for each period. The activities listed above are represented by Y_j in the mathematical model. Each of the activities mentioned above are associated with a cost represented by c_j in the mathematical model.

To minimize costs, a farmer chooses the option (e.g. spreading) that has the lowest cost up to the limit (or constraint) on the amount of litter that can be handled by that method. Then, the model selects the next lowest cost disposal method up to its maximum capacity before using the most expensive option.

4.6 Stage 4: Combining Least Cost Diet Results With Litter Disposal Results

The final phase combines least cost diet results with the litter disposal results to calculate total costs for each dietary treatment under each of the four scenarios. This enables one to determine the least cost overall strategy.

CHAPTER 5

DATA REVIEW

5.1 Data From Diet Experiments

The main source of data used were acquired from the dietary experiments carried out by Drs. Blair and Jacobs as described in section 3.1.2. Numerous observations from the experiments were collected but the relevant ones for this analysis included:

(i) Feed intake

(ii) Nitrogen output

(iii) Manure excreta

(iv) % Litter moisture

(v) % Nitrogen in litter

The data mentioned above were collected for each of the 8 dietary treatments. Some of the data were collected on a daily basis and some, such as the % Litter Moisture level, was collected at 2 weeks to represent the starter phase (0-3 weeks) and at 5 weeks to represent the grower phase (4-6 weeks). This data is presented below in table 5.1.

Table 5.1 Broiler Experiment Data

	Starter Phase		**Grower Phase**		*Final*	*% Litter*	*Total N as*
Diet #	*Feed (g/bird/day)*	*N output (g/bird/day)*	*Feed (g/bird/day)*	*N output (g/bird/day)*	*bird wt. (kg)*	*Moisture (%)*	*% of DM (%)*
1	66	0.93	173.8	2.18	2.458	33.40	5.04
2	67	0.79	156.4	1.58	2.410	31.30	4.23
3	64	0.66	155.5	1.58	2.422	31.15	3.98
4	67	0.62	172.6	1.63	2.348	32.40	3.35
5	66	0.93	155.1	1.63	2.416	30.00	3.59
6	67	0.79	166.2	2.22	2.419	31.70	4.78
7	64	0.66	177.5	2.12	2.468	35.40	4.46
8	67	0.62	174.1	2.30	2.425	30.55	4.59

Source: Blair and Jacobs

The data presented above is daily data for a single bird. Since the problem will be modeled on a cycle basis, the data above is more informative when it is transformed to represent one cycle (6 weeks) and for the whole flock (35,000 birds) as shown below in table 5.2.

Table 5.2 Broiler Experiment Data per Cycle (6 Weeks) per Flock (35,000 birds)

	Starter Phase		**Grower Phase**		**Total**		
Diet #	*Feed*	*N output*	*Feed*	*N output*	*Feed*	*N output*	*Bird Weight*
	(kg/cycle)	*(kg/cycle)*	*(kg/cycle)*	*(kg/cycle)*	*(kg/cycle)*	*(kg/cycle)*	*(kg/cycle)*
1	48510	683.55	127743.0	1602.30	176253.0	2285.85	86030
2	49245	580.65	114954.0	1161.30	164199.0	1741.95	84350
3	47040	485.10	114292.5	1161.30	161332.5	1646.40	84770
4	49245	455.70	126861.0	1198.05	176106.0	1653.75	82180
5	48510	683.55	113998.5	1198.05	162508.5	1881.60	84560
6	49245	580.65	122157.0	1631.70	171402.0	2212.35	84665
7	47040	485.10	130462.5	1558.20	177502.5	2043.30	86380
8	49245	455.70	127963.5	1690.50	177208.5	2146.20	84875

Source: Blair and Jacobs

Feedstuff Composition

The feed ingredients used in this analysis are those common to British Columbia farmers. Since it is not practical to analyze each batch of feedstuff for its nutrient content, reliance must be placed on feedstuff composition data that have been compiled from many laboratory analyses and the standard data used in poultry as published by the National Research Council (NRC). Since feedstuffs vary in composition, the NRC nutrient values (Appendix I, Table 3) are averages reflecting the concentrations of nutrients most likely to be present in the feedstuffs.

From the nutritional point of view, there is no "best" diet formula in terms of ingredients that are used. Ingredients should therefore be selected on the basis of availability, price, and the quality of the nutrients they contain.

Diet Requirements

Diet requirements vary according to whether birds are in the starter phase (0-3 weeks) or in the grower phase (3-6 weeks). The diet requirements are also determined by the NRC for the particular type of bird raised. The requirements shown below in Table 5.3 are the NRC values for broiler diets. The NRC values are generally minimum levels that satisfy general production activities and prevent deficiency syndromes.

Table 5.3: Diet Requirements for Broilers

Diet Requirement	% in Starter Phase	% in Grower Phase
Metabolizable Energy	3200 cal/kg	3200 cal/kg
Crude Protein	21%	18%
Lysine	1.1%	1.1%
Methionine	0.5%	0.5%
Methionine + Cystine	0.9%	0.9%
Threonine	0.8%	0.8%
Tryptophan	0.2%	0.2%
Available Phosphorus	0.45%	0.45%
Total Phosphorus	0.45%	0.45%
Calcium	1.0%	1.0%
Crude Fibre	2.4%	2.4%
Crude Fat	7.0%	7.0%

Source: NRC (1994)

Feed Prices

Feed Ingredient prices vary depending on the season and availability but there are several substitutes which can be used as long as the diet requirements are attained. The feed prices quoted below in table 5.4 are the current market prices from a local cooperative. These are the prices a farmer would pay if s/he wanted to mix her/his own feed at the farm. The prices for the supplemental amino acids are also the current prices from the cooperative (July 1995).

Table 5.4: Feed Ingredient Prices

Feed Ingredient	Price per tonne ($)
Corn	$225.00
Wheat	$230.00
Soybean Meal	$347.00
Meat meal	$381.00
Limestone	$80.00
Dicalcium Phosphate	$90.00
L-LYS	$3000.00
DL-MET	$5000.00
L-THR	$6000.00
L-TRY	$30000.00
A/V Fat	$600.00
Medication & Coccidiostat	$16.00
Mineral Premix	$3500.00

Source: East Chilliwack Cooperative

5.2 Manure Land Application Rates

The manure land application rates recommended by the BCMAFF are to promote crop production and soil improvement while minimizing any hazard to the environment. Table 5.5 below gives recommended rates for manure application in the Fraser Valley which are based on the nitrogen requirement of the crop. The amount of manure applied each year should be governed by the amount of nitrogen removed by the crop[3]. If the amount of nitrogen applied in manure exceeds crop needs, then over time, nitrogen losses to the environment will be excessive.

Nitrogen Removal Rates

Table 5.5: Crop nitrogen removal rates

Crop	**N removal (kg/year)**
Grass	300
Raspberries	100
Cabbage	220
Cauliflower	100
Silage Corn	245

Source: BCMAFF, 1991.

Since fertilized grass and raspberries are the most common crops grown in the region, we make an assumption that half the cropland is used to grow grass and the other half is used to grow raspberries. In considering scenario 1 where the cropland is 7.7 ha (19 acres), 3.85 ha are used for growing grass and 3.85 ha are used for growing raspberries and for scenario 2 where there are 4.9 ha (12 acres) of cropland, 2.45 ha are used for growing grass and 2.45 ha are used for growing raspberries. Therefore, the amount of nitrogen taken up by crops annually is:

Scenario 1: (3.85x300) + (3.85x100) = 1540 kg/year

Scenario 2: (2.45x300) + (2.45x100) = 980 kg/year

[3] It is assumed here that the nitrogen supply for these crops comes only from by manure and no extra inorganic fertilizer is used to supply nitrogen.

This implies that the farmer is able to apply 1540 kg of nitrogen per year on the land in scenario 1 and 980 kg of nitrogen in scenario 2.

Conversion of Nitrogen Output to Litter Amount

The data collected for this study is in terms of nitrogen production as shown in table 5.2. The data required for the model should be in terms of litter production since the storage costs, spreading costs, and transportation costs are all calculated on the basis of litter production. Since the litter data is not available, it is therefore necessary to calculate backwards from the amount of nitrogen produced to the amount of litter produced using the available data on percent nitrogen in dry matter (%N in DM), and percent moisture content of the litter.

Table 5.2 gives the total amount of nitrogen produced per cycle and table 5.1 gives the percent of nitrogen in the dry matter (%N in DM) and the percent moisture content of the litter. The following method was used to calculate the amount of litter produced and the actual percentage of nitrogen present in the litter.

As stated in section 1.1, there is considerable loss of nitrogen by volatilization for manure in storage (10%-50%). It is estimated that there is a nitrogen loss of 22% for poultry manure in storage, leaving only 78% of the excreted nitrogen at the end of the 6 week cycle. Therefore:

$$N_F = 0.78\ N_T \qquad (5.1)$$

N_F = Final amount of nitrogen in litter at the end of the cycle

N_T = Total amount of nitrogen excreted

By using the data on percent nitrogen in dry matter the amount of dry matter litter was calculated as follows.

$$L_{DM} = N_F / N_{DM} \qquad (5.2)$$

L_{DM} = Amount of litter as dry matter

N_{DM} = Percent nitrogen in dry matter

By using the data on percent of moisture in litter, the total amount of litter was calculated as follows.

$$L_T = L_{DM}/1\text{-}M_L \qquad (5.3)$$

L_T = Total amount of litter produced

M_L = Percent of moisture in litter

Using the information derived above, the actual amount (%) of nitrogen in the litter was calculated as follows.

$$N_L = (N_F/L_T)100 \qquad (5.4)$$

N_L = Percentage of nitrogen in litter

The figures calculated above are presented below in table 5.6 for each dietary treatment.

Table 5.6: Nitrogen Conversion to Litter (per cycle)

Diet. Trtmt.	N_T (kg)	N_F (kg)	L_{DM} (kg)	L_T (kg)	N_L (%)
1	2285.85	1782.96	35376.25	53117.49	3.36
2	1741.95	1358.72	32121.06	46755.55	2.91
3	1646.40	1284.19	32266.13	46864.39	2.74
4	1653.75	1289.93	38505.22	56960.39	2.26
5	1881.60	1467.65	40881.56	58402.23	2.51
6	2212.35	1725.63	36101.11	52856.67	3.26
7	2043.30	1593.77	35734.84	55317.09	2.88
8	2146.20	1674.04	36471.37	52514.58	3.19

From the data above, the amount of litter produced annually and the litter equivalent of nitrogen to be spread on the land can be calculated as follows.

$$L_A = (L_T)6 \qquad (5.5)$$

L_A = Annual amount of litter produced

The amount of litter corresponding to 1540 kg of N (scenario 1) and 980 kg of N (scenario 2) was calculated for each dietary treatment, as shown below.

$$L_{S1} = 1540/\, N_L \qquad (5.6)$$

L_{S1} = Litter equivalent for scenario 1

$$L_{S2} = 980/\, N_L \qquad (5.7)$$

L_{S2} = Litter equivalent for scenario 2

The data for L_{S1} and L_{S2} is presented below in table 5.6 for each dietary treatment.

Table 5.7: Annual Litter Spread on Land

Dietary Treatment	Litter Produced (tonnes)	Litter Spread on Land (tonnes)	
		Scenario 1 (1540 Kg N) (L_{S1})	Scenario 2 (980 kg N) (L_{S2})
1	318.70	45.9	29.8
2	280.53	53.0	33.6
3	281.19	56.2	35.8
4	341.76	68.0	43.3
5	350.41	61.3	39.0
6	317.14	47.2	30.0
7	331.90	53.5	34.0
8	315.09	48.3	30.7

The amount of litter that is spread on the land is evenly distributed so that half of it is spread in the spring and the other half in the fall. For example, in scenario 1 of dietary treatment #1, 22.95 tonnes of litter is spread in the spring and 22.95 tonnes of litter is spread in the fall for a total of 45.9 tonnes of litter spread per year.

5.3 Litter Disposal Costs

The litter disposal costs have been discussed in section 2.4.1 so this section will just state the costs. A breakdown of the costs is given in appendix I, Table 2.

Storage Costs	$21.43 per tonne of litter
Spreading Costs	$25.30 per tonne of litter
Transportation Costs	$29.49 per tonne of litter

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Dietary Treatment (Stage 1)

The results calculated from stage 1 of the model are presented in Appendix III, Tables 1-8. These tables show the least cost diet rations for each of the eight dietary treatments. It can be seen that the percentage of the various feed ingredients is quite similar for all the eight dietary treatments with the exception of a couple of the rations, starter rations for dietary treatment #1 and #5. The common aspect between these two dietary treatments is the high crude protein (25% CP) level in both of the starter rations. These two rations also contain a high amount of A/V fat resulting in a high level of crude fat in the diet, (9.8%, about 1.4 times the recommended amount). In order to attain the high level of crude protein demanded by these two rations the model allocates high protein feed ingredients such as wheat and L-LYS in high amounts at the expense of lower valued crude protein ingredients such as corn. Since corn has a higher energy value than wheat 3.35 cal/kg to 2.57 cal/kg respectively, a substitute energy source is required in the rations. The A/V fat supplies the energy (8.36 cal/kg) but at the same time it also supplies an excess amount of crude fat to the rations. This explains the high level of A/V fat in the rations.

All the other dietary treatments have almost the same composition in terms of feed ingredients with just some minor differences. Wheat is used only in small amounts in dietary treatments that demand higher protein levels (21% CP) and those that have control or low amino acid levels. In dietary treatments that demand higher amino acid levels, no wheat is used at all except for starter rations of dietary treatments #1 and #5. Almost all the dietary treatments use MET and THR except those that have low levels of amino acids (-10%). L-LYS is used only in the starter ration of dietary treatments #1 and #5. TRY was not used in any of the dietary treatments due to its high cost of $30/kg. L-LYS is not used much because it does not contain a very high content of crude protein (75% CP and 75% LYS) as compared to the other amino acids such as MET (99% CP and 99% MET) and THR (72% CP and 98.5% THR), which contain higher proportions of crude protein as well as a high proportion of their respective amino acids.

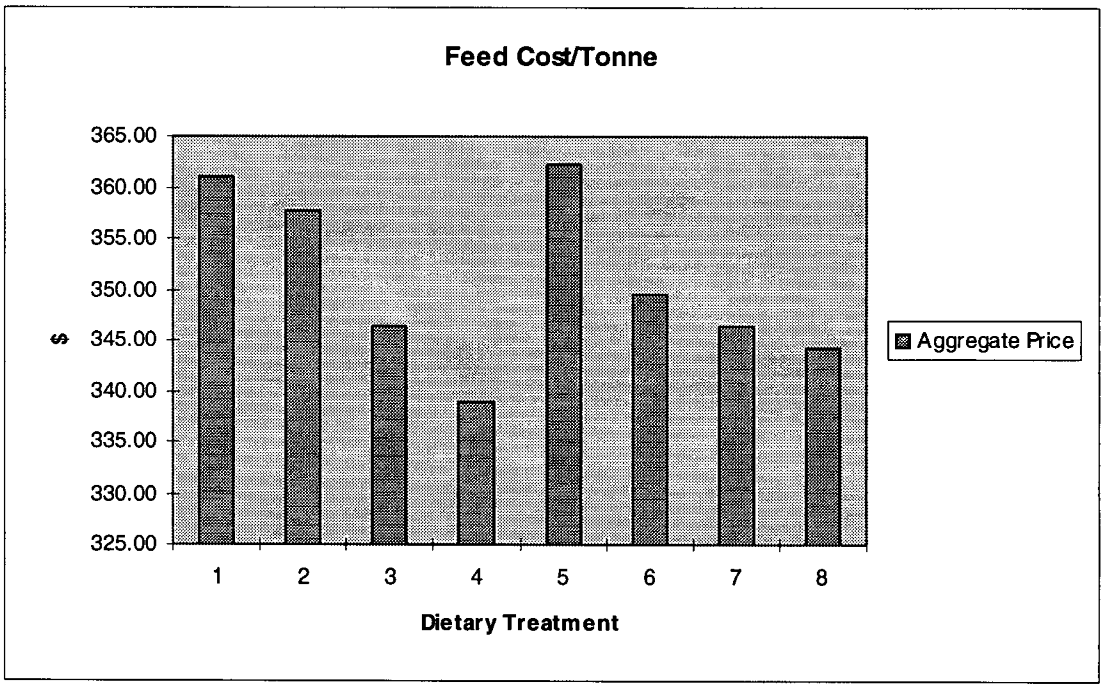
Dietary treatments that are generally higher in crude protein and amino acids have a higher cost than those that have lower levels of these nutrients suggesting a positive correlation between the crude protein level and feed cost, and between amino acid level and the feed cost too. This is due to the fact that feed ingredients that have a higher crude protein value are generally more expensive than ones with lower values.

Table 6.1 Feed Cost Results

Dietary Treatment #	Aggregate Cost/Tonne ($)	Annual Feed Cost ($)	Feed Cost/kg of Chicken Produced (cents)
1	360.99	381,757.40	73.96
2	357.66	352,364.49	69.62
3	346.33	335,248.11	65.91
4	338.98	358,175.42	72.64
5	362.24	353,200.73	69.62
6	349.55	359,480.96	70.77
7	346.33	368,844.20	71.17
8	344.30	366,075.86	71.89

By observing the aggregate prices, dietary treatments #1 and #5 ($360.99/tonne and $362.24/tonne respectively) are much more expensive than the other dietary treatments. These two dietary treatments contain the highest levels of crude protein at 25% CP for the starter rations. The rest of the dietary treatments range in price from $338.98/tonne for dietary treatment #4 to $357.66/tonne for dietary treatment #2. On the basis of feed price alone, one would choose dietary treatment #4 as the best diet because it has the lowest cost at $338.98/tonne. This dietary treatment contains low levels of crude protein (21% CP in the starter ration and 18% in the grower ration) and low levels of amino acids (-10% of the standard level).

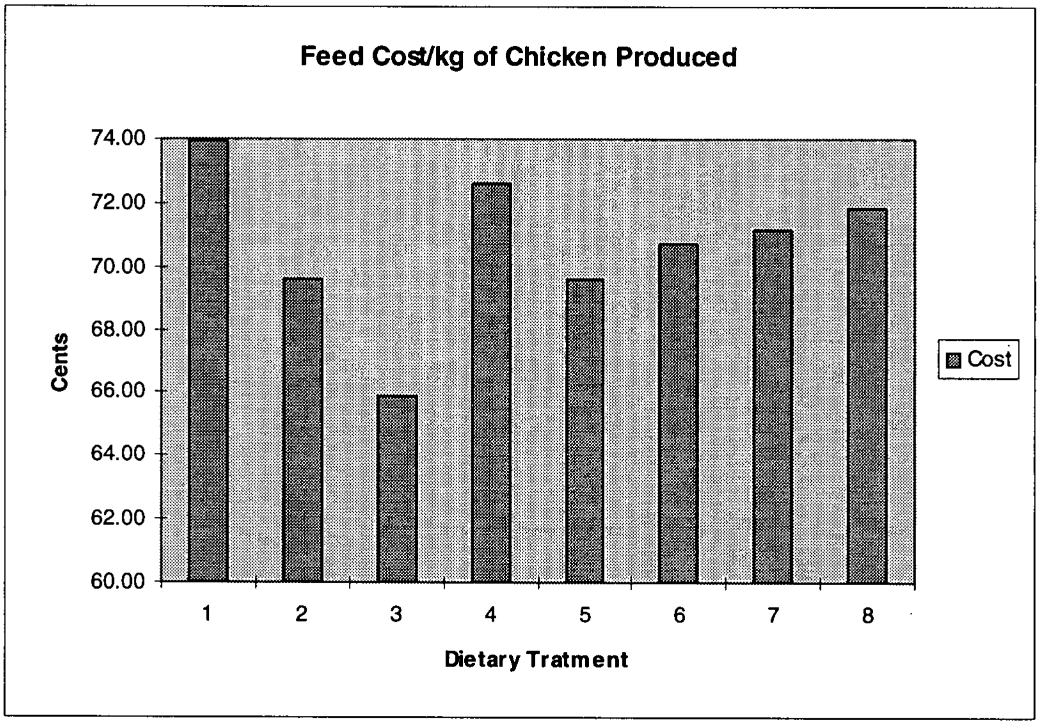
Figure 6.1: Aggregate Feed Cost/Tonne



In terms of annual feed costs (cost/tonne multiplied by the actual amount of feed consumed), dietary treatment #1 has the highest cost at $381,757 and dietary treatment #3 has the lowest cost at $335, 364. But the measures above are not sufficient to determine which is the most efficient dietary treatment since each diet has a different production performance. A true measure of the most efficient dietary treatment is one that has the lowest cost *per kg of chicken produced.* The figures for this measure are given in column 4 of table 6.1 above. The values for this range from a high of 73.96 cents/kg of chicken produced for dietary treatment #1 to a low of 65.91 cents/kg of chicken produced for dietary treatment #3. By using this criteria the model shows that dietary treatment #3 is the most efficient as illustrated by figure 6.1 below. Feed efficiency is accounted for by taking into account the different amounts of feed consumed for each dietary treatment and also considering the bird weight at the end of the cycle for each dietary treatment.

These figures are close to those used in the calculation of the Cost of Production Formula (C.O.P.). The average COP for the years 1991-1994 was 54.2 cents/kg of chicken (CCMA, 95). The cost of production figures in this study are slightly higher due to the fact that the birds in the experiments were fed until they had a final body weight of about 2.4 kg whereas most farms sell their birds at about 1.9 kg. When this factor is taken into consideration, the experimental feed rations fall in the range of 53 cents/kg of chicken produced

Figure 6.2: Feed Cost/kg of Chicken Produced



6.2 LITTER DISPOSAL COSTS

The litter disposal cost is determined by a combination of the total amount of litter produced and the nitrogen (N) content of the litter. Table 6.2 below gives the total amount of litter and nitrogen produced by each dietary treatment. A look at the table below suggests a weak positive correlation between the crude protein level in the diet and the amount of litter produced. The figures also imply a negative correlation between the amino acid levels and the amount of litter produced. Dietary treatment #5 resulted in the highest amount of litter, producing 350 tonnes of litter per year while dietary treatments #2 and #3 produced the least amount of litter at 280 tonnes and 281 tonnes of litter respectively, per year. Dietary treatments with high levels of crude protein and low levels of amino acids seem to produce more litter than dietary treatments containing low levels of crude protein and supplemented with amino acids. This relationship seems to hold for nitrogen as well.

Table 6.2: Annual Litter and Nitrogen Produced

Dietary Treatment #	Litter (Tonnes)	Nitrogen (Tonnes)
1	318.70	13.72
2	280.53	10.45
3	281.19	9.88
4	341.76	9.92
5	350.41	11.29
6	317.14	13.27
7	331.90	12.26
8	315.09	12.88

Nitrogen levels are highest in dietary treatment #1 at about 14 tonnes per year and lowest in dietary treatments #3 and #4 with about 10 tonnes per year. These results suggest that there is higher nitrogen retention in the dietary treatments which have lower crude protein levels and higher amino acid levels implying that the feed is used more efficiently by the birds.

The more important factor being considered in this thesis is the actual cost of litter disposal. These costs are shown below in table 6.3 for each dietary treatment and litter disposal scenario.

Table 6.3: Annual Litter Disposal Costs

Dietary Treatment #	*Scenario 1a*	*Scenario 1b*	*Scenario 2a*	*Scenario 2b*
1	9203.60	13328.90	9273.40	13398.70
2	8050.21	11681.61	8131.51	11762.91
3	8055.29	11694.39	8140.89	11780.09
4	9797.98	14221.48	9901.58	14325.08
5	10077.87	14613.27	10171.27	14706.57
6	9155.14	13260.24	9227.04	13332.14
7	9568.50	13864.70	9650.00	13946.10
8	9089.84	13167.74	9163.44	13241.34

Considering the various litter disposal scenarios, one can see that there is not much difference between the scenario for using 7.7 ha of land or 4.9 ha of land. The difference in cost between using 7.7 ha of land and 4.9 ha of land is about 1% of the total disposal cost, suggesting that only a small portion of the litter can be spread on the land and the major portion is stored or transported off farm. This hypothesis is supported by the fact that only about 14% to 19% of the litter is spread on the land when 7.7 ha of land is used and between 9% to 12% when 4.9 ha is used (see Table 5.7). But there is a big difference in the scenarios where the litter can be transported off the farm all year round (scenarios 1a and 2a) or only in the spring and fall (scenarios 1b and 2b). When the litter is transported off the farm all year round, the cost is about 30% less than the scenario where litter is transported off the farm in the spring and fall only. This result suggests that litter storage accounts for a big portion of the litter disposal costs implying that a large portion of the litter is stored or litter storage costs are very high , or both. In this case the amount of litter stored as compared to that which is spread on the land is high.

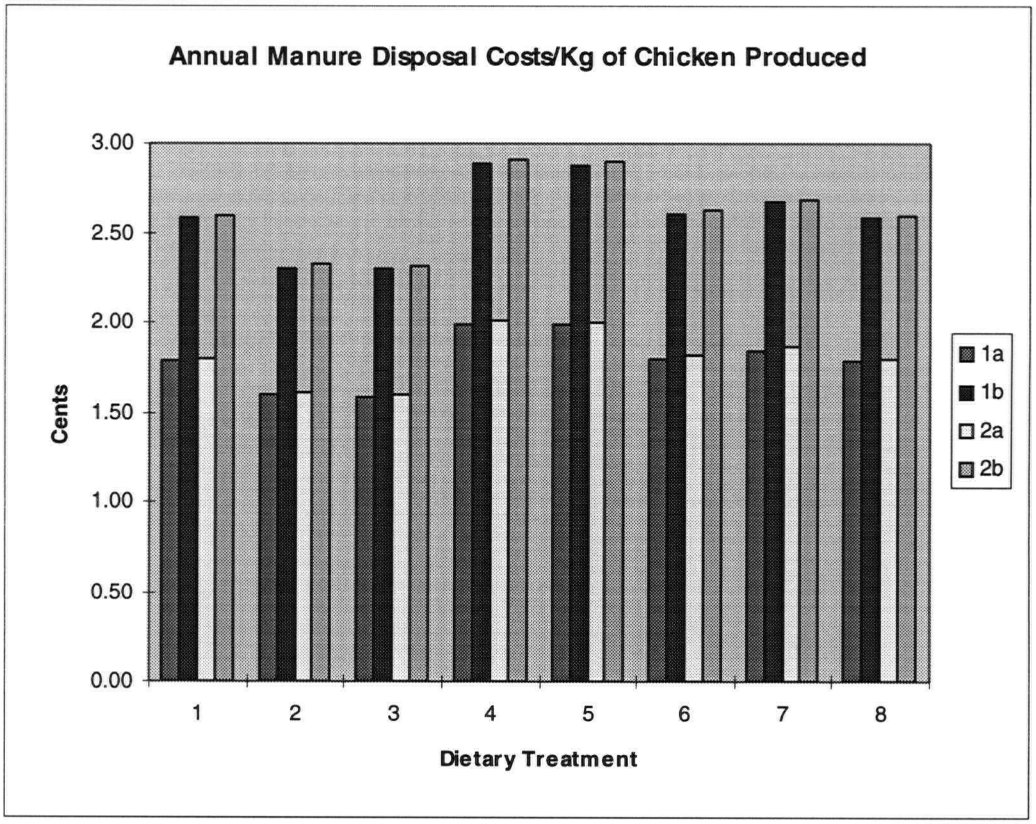
The table above shows that dietary treatment #5 has the highest disposal cost while dietary treatments #2 and #3 have the lowest costs. The figures above are more meaningful when they are presented in terms of chicken production (*per kilogram of chicken produced*). These figures are shown below in table 6.4 for each dietary treatment and each scenario.

Table 6.4: Annual Litter Disposal Costs Per Kg of Chicken Produced

Dietary Treatment #	*Scenario 1a (cents)*	*Scenario 1b (cents)*	*Scenario 2a (cents)*	*Scenario 2b (cents)*
1	1.78	2.58	1.80	2.60
2	1.59	2.31	1.61	2.32
3	1.58	2.30	1.60	2.32
4	1.99	2.88	2.01	2.91
5	1.99	2.88	2.00	2.90
6	1.80	2.61	1.82	2.62
7	1.85	2.68	1.86	2.69
8	1.78	2.59	1.80	2.60

The figures above show that dietary treatments #4 and #5 are the most expensive while dietary treatments #2 and #3 are the least expensive. Figure 6.2 below gives a more visual perspective of the same results.

Figure 6.3: Annual Litter Disposal Cost/kg of Chicken Produced



6.3 COMBINED FEED AND LITTER DISPOSAL COSTS

Considering that the dietary treatment used has a direct effect on litter disposal costs and also that feed costs constitute the major portion of overall chicken production (about 50%), it is important to consider the two aspects together. These results are presented below in table 6.5 in absolute terms and in table 6.6 on a production basis (cost/kg of chicken produced).

Table 6.5: Combined Annual Feed and Litter Disposal Costs

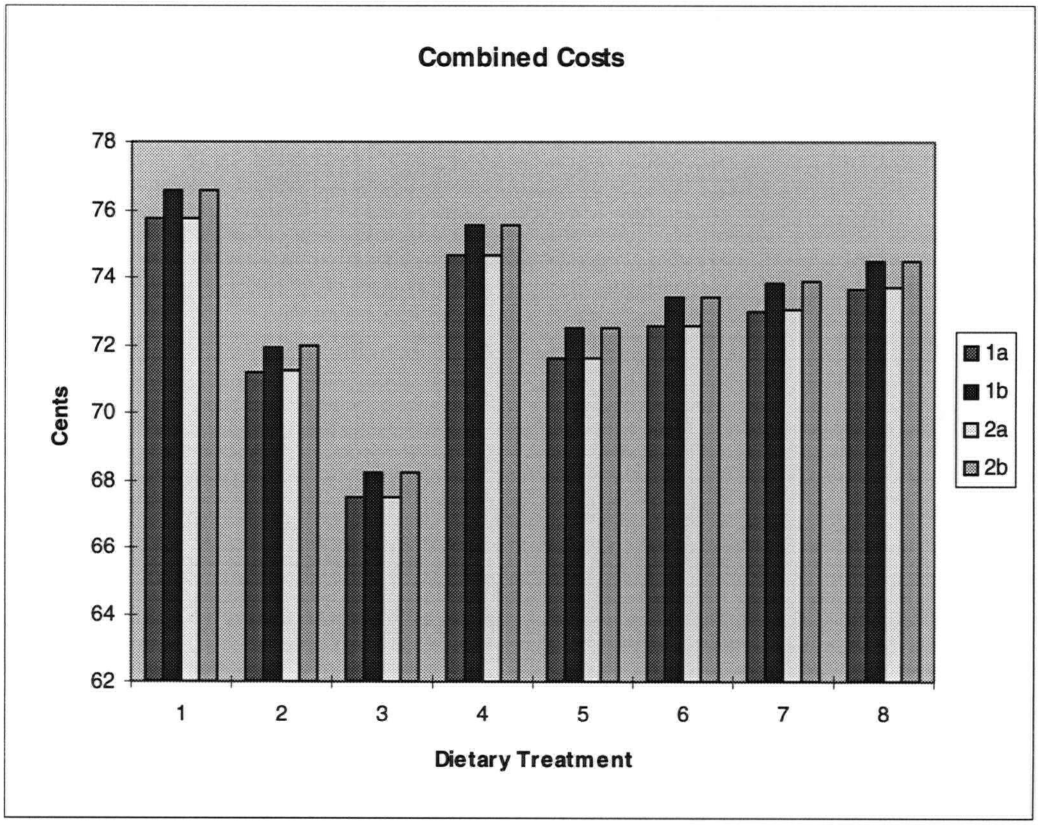
Dietary Treatment #	*Scenario 1a ($)*	*Scenario 1b ($)*	*Scenario 2a ($)*	*Scenario 2b ($)*
1	390961.0	395086.3	391030.8	395156.1
2	360414.7	364046.1	360496.0	364127.4
3	343303.4	346942.5	343389.0	347028.2
4	367973.4	372396.9	368077.0	372500.5
5	363278.6	367814.0	363372.0	367907.3
6	368636.1	372741.2	368708.0	372813.1
7	378412.7	382708.9	378494.2	382790.3
8	375165.7	379243.6	375239.3	379317.2

Table 6.6: Combined Annual Feed and Litter Disposal Costs Per kg of Chicken Produced

Dietary Treatment #	*Scenario 1a (cents)*	*Scenario 1b (cents)*	*Scenario 2a (cents)*	*Scenario 2b (cents)*
1	75.74	76.54	75.75	76.55
2	71.21	71.93	71.23	71.95
3	67.50	68.21	67.51	68.23
4	74.63	75.52	74.65	75.55
5	71.60	72.50	71.62	72.51
6	72.57	73.38	72.58	73.39
7	73.01	73.84	73.03	73.86
8	73.67	74.47	73.68	74.49

When these two aspects are considered together, the most expensive dietary treatment is #1 at $360,961 per year and the least expensive is dietary treatment #3 at $343,300 per year. Taking production performance into consideration, the most expensive dietary treatment is #1 at 75.74 cents and the least expensive is dietary treatment #3 at 67.50 cents. Most of the other dietary treatments fall in the range between 71 cents and 73 cents. These results are illustrated more graphically by figure 6.3 below.

Figure 6.4: Combined Feed and Litter Disposal Costs/kg of Chicken Produced



These results show clearly that the most efficient dietary treatments are #3 followed by #2 and the most expensive are #1 followed by #4. This shows that it is more efficient to use lower levels of crude protein in the diet and supplement the diet with amino acids. The birds utilize the feed more efficiently thereby resulting in less nitrogen excreted in the litter. Dietary treatments #3 and #2 both have 21% crude protein in the starter phase and 18% crude protein in the grower phase. Dietary treatment #3 contains standard levels of amino acids while dietary treatment #2 contains supplemental amino acids (+10%).

These two dietary treatments are the most efficient but #2 is a bit more expensive due to the higher levels of amino acids which are quite expensive.

Manure disposal costs as a fraction of feed costs are quite small and falls in the range of 2% to 4%. The feed costs are definitely the significant factor in the combined costs.

6.4 Shadow Prices

The primal problem in linear programming always has a dual problem that provides useful additional information. The primal problem will assist the farmer in deciding which activity to select and how much of each to use to optimize the objective. The optimal solution can be improved only if the farmer is able to acquire additional units if the fixed resources. If the additional units are used at an optimum level, then each resource will have a unique rental value. In linear programming, these values are called shadow prices. If a resource is not fully utilized in the optimal solution, then the shadow price of the resource is zero.

(a) Feed Cost Shadow Prices

The shadow prices for the feed cost minimization problem are presented in Appendix IV, Table 1. These values indicate how much the value of the objective function would change if an additional unit of the resource were used. For example, in dietary treatment #1, increasing the metabolizable energy constraint by one unit (1 cal/kg), would increase the cost of the feed by \$ 0.16, and increasing the same constraint for dietary treatment #3 would increase the feed cost by \$ 0.07.

(b) Manure Disposal Shadow Prices

The shadow prices for manure disposal are presented in appendix IV, Table 2 to Table 5. These values indicate by how much the value of the objective function by use of an extra unit of the constraint. In scenarios 1(a) and 2(a), The shadow price for the land application constraint is 4.19 in all the periods. This means that the manure disposal cost would increase by $4.19 if an extra tonne of manure is disposed by land application. This value of 4.19 is the difference in cost between the cost of transportation and land application. The shadow price for storage is zero in all periods except the last one. This is because the storage constraint is binding only in the last period. The shadow price for the transportation is zero in all periods since this constraint is not binding in any period.

In scenarios 1(b) and 2(b) the shadow prices vary quite a lot from period to period since the manure is disposed of using several options instead of only transportation as in scenarios 1(a) and 2(a).

CHAPTER 7

CONCLUSION

New technologies in the production of chicken have strived to produce more and bigger birds in the shortest time possible. Many of these technologies have focused on the nutrition of the bird and consist of diets with high levels of protein. These diets result in the production of litter containing high levels of nitrogen. There is therefore a risk of this nitrogen leaching into the groundwater and becoming an environmental hazard when large quantities of litter are spread onto the land as a fertilizer on a limited land base.

As society becomes more and more concerned about protecting the environment, new production methods and strategies have to be developed that are less harmful to the environment. Recent research has shown that diets that have lower levels of protein in the diet and are supplemented with amino acids are more economical in that they utilize the protein more efficiently. This thesis has shown that dietary treatment #3 with 21% crude protein in the starter ration and 18% crude protein in the grower ration with standard levels of amino acids is the most efficient at 65.91 cents/kg of chicken produced. Dietary treatment #2 which has the same level of crude protein as #3 but supplemented with amino acids (+10%) is the next most efficient at 69.62 cents/kg of chicken produced. Dietary treatment is #5 with 25% crude protein in the starter ration and 21% crude protein in the grower ration with standard levels of amino acids is the most expensive at 73.96 cents/kg of chicken produced. This shows that dietary .treatments with lower levels of crude protein are generally more efficient. But within this group of lower level crude protein, those with higher levels of amino acids are more expensive due to the high cost of supplemental amino acids.

Not only is a low level protein diet economical as a feed , but it is also more economical in terms of litter disposal. Since the diet is more efficient in utilizing the protein, there is less nitrogen excreted in the litter thereby reducing the risk of nitrogen leaching into the groundwater when the litter is used as a fertilizer. This lower level of nitrogen in the litter creates further savings in terms of litter disposal because a greater amount of litter can be spread on the land as opposed to transporting it off farm, which is a more expensive option. When the feed costs and litter disposal costs are combined, the low level protein diet cost 67.50 cents/kg of chicken produced as compared to 75.74 cents/kg of chicken produced for the higher level protein diet. This difference of 8.24 cents might not seem like much but it is significant in the profit /break-even analysis of the farmer. For a farmer raising 35,000 birds per cycle at 1.9 kg per bird, this translates into savings of $ 32,900 per year by using dietary treatment instead of #5. Manure disposal costs as a fraction of feed costs is very small and insignificant, the driving force in poultry production is still the feed costs.

Technologies that are more environmentally friendly are often thought to be more costly, but this thesis has shown that in this particular case the new technology was cheaper to an individual farmer by a significant amount. There are other greater benefits to society as a whole in terms of improved environmental quality that are not evaluated in this thesis. The adoption of this technology would be beneficial for BC poultry farmers and the lower Fraser Valley society as a whole.

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APPENDIX I

Table 1: Canadian Chicken Supply and Disposition (000 kg)

Year	Production	Consumption	B.C. Production	Canadian Per Capita Consumption (kg)
1975	284646	300442		12.9
1976	322124	337430		14.3
1977	330081	355581		15.0
1978	355314	380104		15.6
1979	401518	419318		17.3
1980	390313	413971		16.8
1981	398216	414604		16.7
1982	397376	425417	36359	16.9
1983	395183	429452	38061	16.9
1984	427401	461457	42120	17.8
1985	472112	499030	45348	19.2
1986	487696	519984	49375	19.8
1987	517748	542390	55249	21.1
1988	523010	569830	58129	21.9
1989	522738	569057	62305	21.4
1990	556472	598753	69896	22.1
1991	559505	603523	71548	22.2
1992	562683	616478	74509	22.3
1993	601854	652250	84310	23.1
1994	685109	715290	96536	25.1

Source: Agriculture and Agri-Food Canada

Table 2: Breakdown of Manure Disposal Costs[4]

Storage

Activity	**Cost ($)**
Barn cleaning	$10.65
Loading to storage	$8.10
Building costs/cycle	$2.68
Total	**$21.43**

Spreading

Activity	**Cost ($)**
Barn Cleaning	$10.65
Unloading to spreader	$8.10
Spreading	$6.55
Total	**$25.30**

Transportation

Activity	**Cost ($)**
Barn Cleaning	$10.65
Unloading to truck	$8.10
Transporting (60 km)	$10.74
Total	**$29.49**

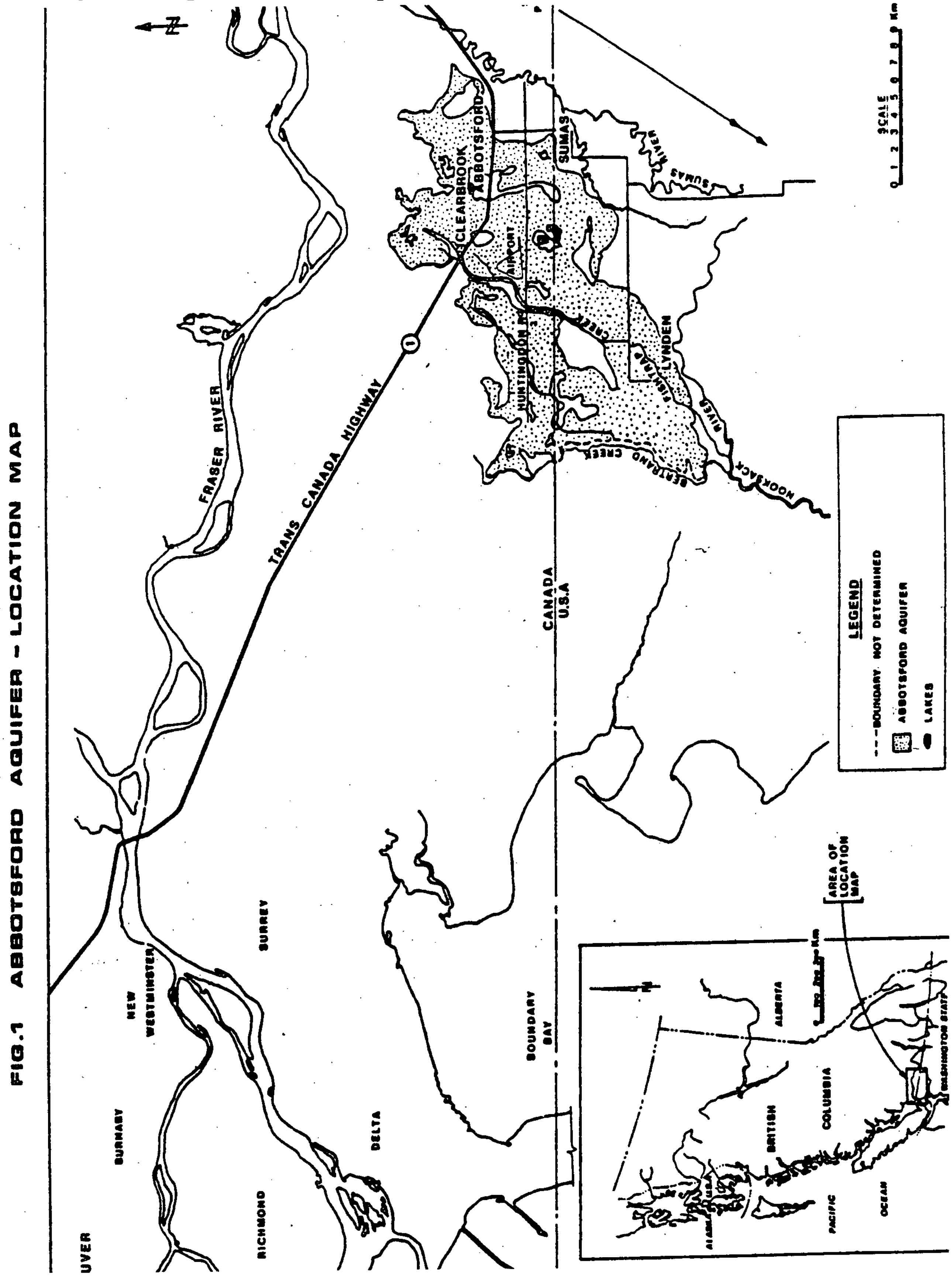
Source: Stennes (1992)

[4] These costs are quoted as $ per tonne of litter.

Table 3: National Research Council Feedstuff Composition

Feedstuff/Nutrient	Corn	Wheat	Soybean Meal	Meat Meal	Limestone	Dicalcium Phosphate
Metabolizable Energy cal/kg)	3.35	2.568	2.44	2.195		
Crude Protein (%)	8.5	15.3	48.5	54.4		
Lysine (%)	0.26	0.59	2.96	3		
Methionine (%)	0.18	0.23	0.67	0.75		
Methionine + Cystine (%)	0.36	0.6	1.39	1.41		
Threonine (%)	0.29	0.5	1.87	1.74		
Tryptophan (%)	0.06	0.1	0.74	0.36		
Available Phosphorus (%)	0.13	0.2	0.37	4		
Total Phosphorus (%)	0.28	0.14	0.22	4.1		20
Calcium (%)	0.02	0.04	0.27	8.27	38	23
Crude Fibre (%)	2.2	2.6	3.9	2.7		
Crude Fat (%)	3.8	1.5	0.5	6		

Figure 1: Map of Abbotsford Aquifer



Appendix II: LP Tableaux

Table 1: Least Cost Feed Tableau

Rows	Nutrient \ Feed Ingredient	Corn	Wheat	Soybean Meal	Meat Meal	Limestone	Dicalcium P	L-LYS	DL-MET	L-THR	L-TRY	A/V Fat	Med & Cocc	Premix	Starter Feed	Corn	Wheat	Soybean Meal
	Broiler Feed Model for Dietary Treatment #3																	
	CP1=21%, CP2=18%																	
	AA1=control, AA2=control																	
1	*Weight (kg)*	**600**	**4.70015**	**247.1321281**	**69.905271**	**9.025519**	**0**	**0**	**2.41515**	**0.4048**	**0**	**50.4169**	**1**	**15**	**1000**	**604.8**	**1E-15**	**247.6101645**
2	*Price ($/kg)*	0.225	0.23	0.347	0.381	0.08	0.09	3	5	6	30	0.6	0.016	3.5		0.225	0.23	0.347
	0-3 weeks																	
3	*Metabolizable Energy (cal/kg)*	3.35	2.568	2.44	2.195							8.36						
4	*Crude Protein (%)*	0.085	0.153	0.485	0.544			0.75	0.99	0.72	0.85							
5	*Lysine (%)*	0.0026	0.0059	0.0296	0.03			0.75										
6	*Methionine (%)*	0.0018	0.0023	0.0087	0.0075				0.99									
7	*Methionine + Cystine (%)*	0.0036	0.006	0.0139	0.0141				0.99									
8	*Threonine (%)*	0.0029	0.005	0.0187	0.0174					0.985								
9	*Tryptophan (%)*	0.0006	0.001	0.0074	0.0036						0.98							
10	*Available Phosphorus (%)*	0.0013	0.002	0.0037	0.04													
11	*Total Phosphorus (%)*	0.0028	0.0014	0.0022	0.041		0.2											
12	*Calcium (%)*	0.0002	0.0004	0.0027	0.0827	0.38	0.23											
13	*Crude Fibre (%)*	0.022	0.026	0.039	0.027													
14	*Crude Fat (%)*	0.038	0.015	0.005	0.06							1						
15	*Medication & Coccidiostat*												1					
16	*Trace mineral and vit premix*													1				
	Ingredient Limits																	
17	*Corn Upper Limit*	-1													0.6			
18	*Corn Lower Limit*	-1													0.2			
19	*Wheat Upper Limit*		-1												0.2			
20	*Wheat Lower Limit*		-1															
21	*Soybean Meal Upper Limit*			-1											0.3			
22	*Soybean Meal Lower Limit*			-1											0.1			
23	*Meat Meal Upper Limit*				-1										0.07			
24	*Meat Meal Lower Limit*				-1													
25	*Starter Feed*	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1			
26	*Starter Feed Limit (kg)*														1			
	3-6 Weeks																	
27	*Metabolizable Energy (cal/kg)*															3.35	2.568	2.44
28	*Crude Protein (%)*															0.085	0.153	0.485
29	*Lysine (%)*															0.003	0.0059	0.0296
30	*Methionine (%)*															0.002	0.0023	0.0087
31	*Methionine + Cystine (%)*															0.004	0.006	0.0139
32	*Threonine (%)*															0.003	0.005	0.0187
33	*Tryptophan (%)*															6E-04	0.001	0.0074
34	*Available Phosphorus (%)*															0.001	0.002	0.0037
35	*Total Phosphorus (%)*															0.003	0.0014	0.0022
36	*Calcium (%)*															2E-04	0.0004	0.0027
37	*Crude Fibre (%)*															0.022	0.026	0.039
38	*Crude Fat (%)*															0.038	0.015	0.005
39	*Medication & Coccidiostat*																	
40	*Trace mineral and vit premix*																	
	Ingredient Limits																	
41	*Corn Upper Limit*															-1		
42	*Corn Lower Limit*															-1		
43	*Wheat Upper Limit*																-1	
44	*Wheat Lower Limit*																-1	
45	*Soybean Meal Upper Limit*																	-1
46	*Soybean Meal Lower Limit*																	-1
47	*Meat Meal Upper Limit*																	
48	*Meat Meal Lower Limit*																	
49	*Grower Feed*															-1	-1	-1
50	*Grower Feed Limit (kg)*																	

Meat Meal	Limestone	Dicalcium P	L-LYS	DL-MET	L-THR	L-TRY	A/V Fat	Med & Cocc	Premix	Grower feed		Requirements	Rows	Nutrient \ Feed Ingredient	Constraints	
69.938913	**9.0172037**	**0**	**0**	**2.41886**	**0.4048**	**0**	**49.7748**	**1**	**15**	**1000**			1	*Weight (kg)*	**1000**	***($/2t of feed)***
0.381	0.08	0.09	3	5	6	30	0.6	0.016	3.5				2	*Price ($/kg)*		**692.743591**
												0-3 Weeks		***0-3 weeks***		
											>=	3.2	3	*Metabolizable Energy (cal/kg)*	3200	3200
											>=	0.21	4	*Crude Protein (%)*	210	212.289162
											>=	0.011	5	*Lysine (%)*	11	11
											>=	0.005	6	*Methionine (%)*	5	5.66188333
											>=	0.009	7	*Methionine + Cystine (%)*	9	9
											>=	0.008	8	*Threonine (%)*	8	8
											>=	0.002	9	*Tryptophan (%)*	2	2.44513687
											>=	0.0045	10	*Available Phosphorus (%)*	4.5	4.5
											>=	0.0045	11	*Total Phosphorus (%)*	4.5	5.09638699
											>=	0.01	12	*Calcium (%)*	10	10
											>=	0.024	13	*Crude Fibre (%)*	24	24.8477992
											>=	0.07	14	*Crude Fat (%)*	70	78.717411
											=	0.001	15	*Medication & Coccidiostat*	1	1
											=	0.015	16	*Trace mineral and vit premix*	15	15
														Ingredient Limits		
											>=	0	17	*Corn Upper Limit*	0	0
											<=	0	18	*Corn Lower Limit*	0	-400
											>=	0	19	*Wheat Upper Limit*	0	195.299849
											<=	0	20	*Wheat Lower Limit*	0	-4.700151
											>=	0	21	*Soybean Meal Upper Limit*	0	52.8678719
											<=	0	22	*Soybean Meal Lower Limit*	0	-147.13213
											>=	0	23	*Meat Meal Upper Limit*	0	0.0947294
											<=	0	24	*Meat Meal Lower Limit*	0	-69.905271
											>=	0	25	*Starter Feed*	0	-1.137E-13
											=	1000	26	*Starter Feed Limit (kg)*	1000	1000
														3-6 Weeks		
2.195							8.36				>=	3.2	27	*Metabolizable Energy (cal/kg)*	3200	3200
0.544			0.75	0.99	0.72	0.85					>=	0.18	28	*Crude Protein (%)*	180	212.234828
0.03			0.75								>=	0.011	29	*Lysine (%)*	11	11
0.0075				0.99							>=	0.005	30	*Methionine (%)*	5	5.66690648
0.0141				0.99							>=	0.009	31	*Methionine + Cystine (%)*	9	9
0.0174					0.985						>=	0.008	32	*Threonine (%)*	8	8
0.0036						0.98					>=	0.002	33	*Tryptophan (%)*	2	2.44699647
0.04											>=	0.0045	34	*Available Phosphorus (%)*	4.5	4.5
0.041		0.2									>=	0.0045	35	*Total Phosphorus (%)*	4.5	5.10577659
0.0827	0.38	0.23									>=	0.01	36	*Calcium (%)*	10	10
0.027											>=	0.024	37	*Crude Fibre (%)*	24	24.8515233
0.06							1				>=	0.07	38	*Crude Fat (%)*	70	78.1928971
								1			=	0.001	39	*Medication & Coccidiostat*	1	1
									1		=	0.015	40	*Trace mineral and vit premix*	15	15
														Ingredient Limits		
										0.7	>=	0	41	*Corn Upper Limit*	0	95.1647162
										0.2	<=	0	42	*Corn Lower Limit*	0	-404.83528
										0.25	>=	0	43	*Wheat Upper Limit*	0	250
											<=	0	44	*Wheat Lower Limit*	0	-1.332E-15
										0.3	>=	0	45	*Soybean Meal Upper Limit*	0	52.3898355
										0.1	<=	0	46	*Soybean Meal Lower Limit*	0	-147.61016
-1										0.07	>=	0	47	*Meat Meal Upper Limit*	0	0.06108695
-1										0.01	<=	0	48	*Meat Meal Lower Limit*	0	-59.938913
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	>=	0	49	*Grower Feed*	0	-2.274E-13
										1	=	1000	50	*Grower Feed Limit (kg)*	1000	1000

Table 2: Litter Disposal Tableau

	Manure Disposal Model for Dietary Treatment #3																	
	DEC-JAN		DEC-JAN				FEB-MAR					APR-MAY					JUN-JUL	
ROWS	Activity	Feed Cost	Man prod 1	Storage 1	Land 1	Transport 1	Man prod 2	Trans. 1-2	Storage 2	Land 2	Transport 2	Man prod 3	Trans. 2-3	Storage 3	Land 3	Transport 3	Man prod 4	Trans. 3-4
1	Weight(t)	968	46.86	0	0	46.86	46.86	0	0	0	46.86	46.86	0	0	28.1	18.76	46.86	0
2	Cost ($/t)	346.33		21.43	25.3	29.49			21.43	25.3	29.49			21.43	25.3	29.49		
3	Feed	1																
4	Manure		1															
5	Man disposal		-1	1	1	1												
6	Storage limit			1														
7	Land limit				1													
8	Transport limit					1												
9	Manure transfer			-1				1										
	FEB-MAR																	
10	Manure						1											
11	Man disposal						-1	-1	1	1	1							
12	Storage limit								1									
13	Land limit									1								
14	Transport limit										1							
15	Manure transfer								-1				1					
	APR-MAY																	
16	Manure											1						
17	Man disposal											-1	-1	1	1	1		
18	Storage limit													1				
19	Land limit														1			
20	Transport limit															1		
21	Manure transfer													-1				1
	JUN-JUL																	
22	Manure																1	
23	Man disposal																-1	-1
24	Storage limit																	
25	Land limit																	
26	Transport limit																	
27	Manure transfer																	
	AUG-SEP																	
28	Manure																	
29	Man disposal																	
30	Storage limit																	
31	Land limit																	
32	Transport limit																	
33	Manure transfer																	
	OCT-NOV																	
34	Manure																	
35	Man disposal																	
36	Storage limit																	
37	Land limit																	
38	Transport limit																	

Storage 4	Land 4	Transport 4	AUG-SEP Man prod 5	Trans. 4-5	Storage 5	Land 5	Transport 5	OCT-NOV Man prod	Trans. 5-6	Storage 6	Land 6	Transport 6			ROWS	DEC-JAN Activity		
0	0	46.86	46.86	0	0	28.1	18.76	46.86	0	0	0	46.86			1	*Weight(t)*		**Min. Cost**
21.43	25.3	29.49			21.43	25.3	29.49			21.43	25.3	29.49			2	*Cost ($/t)*		**343303.4**
													>=	968	3	*Feed*	968	**968**
													>=	46.86	4	*Manure*	46.86	**46.86**
													>=	0	5	*Man disposal*	0	**0**
													<=	150	6	*Storage limit*	150	**0**
													<=	0	7	*Land limit*	0	**0**
													<=	10000	8	*Transport limit*	10000	**46.86**
													>=	0	9	*Manure transfer*	0	**0**
																FEB-MAR		
													>=	46.86	10	*Manure*	46.86	**46.86**
													>=	0	11	*Man disposal*	0	**0**
													<=	150	12	*Storage limit*	150	**0**
													<=	0	13	*Land limit*	0	**0**
													<=	10000	14	*Transport limit*	10000	**46.86**
													>=	0	15	*Manure transfer*	0	**0**
																APR-MAY		
													>=	46.86	16	*Manure*	46.86	**46.86**
													>=	0	17	*Man disposal*	0	**3.55E-16**
													<=	150	18	*Storage limit*	150	**0**
													<=	28.1	19	*Land limit*	28.1	**28.1**
													<=	10000	20	*Transport limit*	10000	**18.76**
													>=	0	21	*Manure transfer*	0	**0**
																JUN-JUL		
													>=	46.86	22	*Manure*	46.86	**46.86**
1	1	1											>=	0	23	*Man disposal*	0	**0**
1													<=	150	24	*Storage limit*	150	**0**
	1												<=	0	25	*Land limit*	0	**0**
		1											<=	10000	26	*Transport limit*	10000	**46.86**
-1				1									>=	0	27	*Manure transfer*	0	**0**
																AUG-SEP		
			1										>=	46.86	28	*Manure*	46.86	**46.86**
			-1	-1	1	1	1						>=	0	29	*Man disposal*	0	**3.55E-16**
					1								<=	150	30	*Storage limit*	150	**0**
						1							<=	28.1	31	*Land limit*	28.1	**28.1**
							1						<=	10000	32	*Transport limit*	10000	**18.76**
					-1				1				>=	0	33	*Manure transfer*	0	**0**
																OCT-NOV		
								1					>=	46.86	34	*Manure*	46.86	**46.86**
								-1	-1	1	1	1	>=	0	35	*Man disposal*	0	**0**
										1			<=	0	36	*Storage limit*	0	**0**
											1		<=	0	37	*Land limit*	0	**0**
												1	<=	10000	38	*Transport limit*	10000	**46.86**

Appendix III: Least Cost Diet Tables

Table 1: Starter and Grower Rations for Dietary Treatment #1

Startert Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	293.79	29.38	0.225	66.10	
Wheat	200.00	20.00	0.23	46.00	
Soybean Meal	300.00	30.00	0.347	104.10	
Meat Meal	70.00	7.00	0.381	26.67	
Limestone	8.58	0.86	0.08	0.69	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	12.35	1.24	3	37.05	
DL-MET	1.60	0.16	5	8.01	
L-THR	0.00	0.00	6	0.00	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	97.67	9.77	0.6	58.60	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**399.74**	**399.74**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	746.02

Table 2: Starter and Grower Rations for Dietary Treatment #2

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	554.22	55.42	0.225	124.70	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	291.68	29.17	0.347	101.21	
Meat Meal	67.51	6.75	0.381	25.72	
Limestone	9.26	0.93	0.08	0.74	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.93	0.29	5	14.64	
L-THR	0.57	0.06	6	3.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	57.83	5.78	0.6	34.70	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**357.66**	**357.66**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	554.22	55.42	0.225	124.70	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	291.68	29.17	0.347	101.21	
Meat Meal	67.51	6.75	0.381	25.72	
Limestone	9.26	0.93	0.08	0.74	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.93	0.29	5	14.64	
L-THR	0.57	0.06	6	3.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	57.83	5.78	0.6	34.70	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**357.66**	**357.66**
				Sum	715.33

Table 3: Starter and Grower Rations for Dietary Treatment #3

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	600.00	60.00	0.225	135.00	
Wheat	4.70	0.47	0.23	1.08	
Soybean Meal	247.13	24.71	0.347	85.75	
Meat Meal	69.91	6.99	0.381	26.63	
Limestone	9.03	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.08	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	50.42	5.04	0.6	30.25	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.46**	**346.46**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	692.74

Table 4: Starter and Grower Rations for Dietary Treatment #4

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	600.00	60.00	0.225	135.00	
Wheat	10.94	1.09	0.23	2.52	
Soybean Meal	242.75	24.28	0.347	84.23	
Meat Meal	70.00	7.00	0.381	26.67	
Limestone	9.03	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	1.53	0.15	5	7.64	
L-THR	0.00	0.00	6	0.00	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.76	4.98	0.6	29.85	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**339.15**	**339.15**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	609.74	60.97	0.225	137.19	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	245.22	24.52	0.347	85.09	
Meat Meal	70.00	7.00	0.381	26.67	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	1.52	0.15	5	7.62	
L-THR	0.00	0.00	6	0.00	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	48.49	4.85	0.6	29.09	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**338.91**	**338.91**
				Sum	678.06

Table 5: Starter and Grower Rations for Dietary Treatment #5

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	293.79	29.38	0.225	66.10	
Wheat	200.00	20.00	0.23	46.00	
Soybean Meal	300.00	30.00	0.347	104.10	
Meat Meal	70.00	7.00	0.381	26.67	
Limestone	8.58	0.86	0.08	0.69	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	12.35	1.24	3	37.05	
DL-MET	1.60	0.16	5	8.01	
L-THR	0.00	0.00	6	0.00	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	97.67	9.77	0.6	58.60	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**399.74**	**399.74**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	746.02

Table 6: Starter and Grower Rations for Dietary Treatment #6

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	554.22	55.42	0.225	124.70	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	291.68	29.17	0.347	101.21	
Meat Meal	67.51	6.75	0.381	25.72	
Limestone	9.26	0.93	0.08	0.74	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.93	0.29	5	14.64	
L-THR	0.57	0.06	6	3.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	57.83	5.78	0.6	34.70	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**357.66**	**357.66**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	703.94

Table 7: Starter and Grower Rations for Dietary Treatment #7

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	600.00	60.00	0.225	135.00	
Wheat	4.70	0.47	0.23	1.08	
Soybean Meal	247.13	24.71	0.347	85.75	
Meat Meal	69.91	6.99	0.381	26.63	
Limestone	9.03	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.08	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	50.42	5.04	0.6	30.25	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.46**	**346.46**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	692.74

Table 8: Starter and Grower Rations for Dietary Treatment #8

Starter Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	600.00	60.00	0.225	135.00	
Wheat	10.94	1.09	0.23	2.52	
Soybean Meal	242.75	24.28	0.347	84.23	
Meat Meal	70.00	7.00	0.381	26.67	
Limestone	9.03	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	1.53	0.15	5	7.64	
L-THR	0.00	0.00	6	0.00	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.76	4.98	0.6	29.85	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**339.15**	**339.15**

Grower Ration

Feed Ingredient	*Amount (kg)*	*% in Diet*	*Price/kg*	*Total Cost*	
Corn	604.84	60.48	0.225	136.09	
Wheat	0.00	0.00	0.23	0.00	
Soybean Meal	247.61	24.76	0.347	85.92	
Meat Meal	69.94	6.99	0.381	26.65	
Limestone	9.02	0.90	0.08	0.72	
Dicalcium P	0.00	0.00	0.09	0.00	
L-LYS	0.00	0.00	3	0.00	
DL-MET	2.42	0.24	5	12.09	
L-THR	0.40	0.04	6	2.43	
L-TRY	0.00	0.00	30	0.00	
A/V Fat	49.77	4.98	0.6	29.86	
Med & Cocc	1.00	0.10	0.016	0.02	
Premix	15.00	1.50	3.5	52.50	
Total	**1000.00**	**100.00**		**346.28**	**346.28**
				Sum	685.43

Appendix IV: Shadow Prices

Table 1: Shdow Prices For Least Cost Feed Model

Dietary Treatment Name	1	2	3	4	5	6	7	8
Metabolizable Energy (cal/kg)	-0.16	-0.08	-0.07	-0.08	-0.16	-0.08	-0.07	-0.08
Crude Protein (%)	-4.98	0.00	0.00	-0.26	-4.98	0.00	0.00	-0.26
Lysine (%)	0.00	-1.64	-0.01	0.00	0.00	-1.64	-0.01	0.00
Methionine (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methionine + Cystine (%)	-0.81	-5.15	-5.08	-4.82	-0.81	-5.15	-5.08	-4.82
Threonine (%)	0.00	-6.19	-6.12	0.00	0.00	-6.19	-6.12	0.00
Tryptophan (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available Phosphorus (%)	0.00	-0.66	-1.02	-0.33	0.00	-0.66	-1.02	-0.33
Total Phosphorus (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium (%)	-2.15	-0.46	-0.28	-0.30	-2.15	-0.46	-0.28	-0.30
Crude Fibre (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crude Fat (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medication & Coccidiostat	-0.75	-0.11	-3.53	-0.05	-0.75	-0.11	-0.04	-0.05
Trace mineral and vit premix	-4.24	-3.60	-0.04	-3.54	-4.24	-3.60	-3.53	-3.54
Corn Upper Limit	0.00	0.00	-0.04	-0.03	0.00	0.00	-0.04	-0.03
Corn Lower Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat Upper Limit	-0.21	0.00	0.00	0.00	-0.21	0.00	0.00	0.00
Wheat Lower Limit	0.00	0.04	0.00	0.00	0.00	0.04	0.00	0.00
Soybean Meal Upper Limit	-1.74	0.00	0.00	0.00	-1.74	0.00	0.00	0.00
Soybean Meal Lower Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat Meal Upper Limit	-2.13	0.00	0.00	0.00	-2.13	0.00	0.00	0.00
Meat Meal Lower Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Starter Feed	-0.74	-0.10	-0.03	-0.04	-0.74	-0.10	-0.03	-0.04
Starter Feed Limit (kg)	1.45	0.10	0.05	0.06	1.45	0.10	0.05	0.06
Metabolizable Energy (cal/kg)	-0.08	-0.08	-0.08	-0.10	-0.08	-0.08	-0.08	-0.08
Crude Protein (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lysine (%)	-1.64	-1.64	-1.64	0.00	-1.64	-1.64	-1.64	-1.64
Methionine (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methionine + Cystine (%)	-5.15	-5.15	-5.15	-5.25	-5.15	-5.15	-5.15	-5.15
Threonine (%)	-6.19	-6.19	-6.19	0.00	-6.19	-6.19	-6.19	-6.19
Tryptophan (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available Phosphorus (%)	-0.66	-0.66	-0.66	-63.64	-0.66	-0.66	-0.66	-0.66
Total Phosphorus (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium (%)	-0.46	-0.46	-0.46	-0.73	-0.46	-0.46	-0.46	-0.46
Crude Fibre (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crude Fat (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medication & Coccidiostat	-0.11	-0.11	-0.11	-0.21	-0.11	-0.11	-0.11	-0.11
Trace mineral and vit premix	-3.60	-3.60	-3.60	-3.70	-3.60	-3.60	-3.60	-3.60
Corn Upper Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Lower Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat Upper Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat Lower Limit	0.04	0.04	0.04	0.02	0.04	0.04	0.04	0.04
Soybean Meal Upper Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soybean Meal Lower Limit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat Meal Lower Limit	0.00	0.00	0.00	-2.31	0.00	0.00	0.00	0.00
Grower Feed	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grower Feed Limit (kg)	0.10	-0.10	-0.10	-0.20	-0.10	-0.10	-0.10	-0.10
Meat Meal Upper Limit	0.00	0.10	0.10	0.36	0.10	0.10	0.10	0.10

Table 2: Shadow Prices For Manure Disposal Model, Scenario 1(a)

Dietary Treatment	1	2	3	4	5	6	7	8
Name								
Metabolizable Energy (cal/kg)	-0.160085672	-0.083168286	-0.074804817	-0.075962885	-0.160085672	-0.083168286	-0.074804817	-0.075962885
Crude Protein (%)	-4.984421626	0	0	-0.263162521	-4.984421626	0	0	-0.263162521
Lysine (%)	0	-1.635941286	-0.012441376	0	0	-1.635941286	-0.012441376	0
Methionine (%)	0	0	0	0	0	0	0	0
Methionine + Cystine (%)	-0.811857384	-5.146754415	-5.076129567	-4.822746283	-0.811857384	-5.146754415	-5.076129567	-4.822746283
Threonine (%)	0	-6.188108498	-6.117125148	0	0	-6.188108498	-6.117125148	0
Tryptophan (%)	0	0	0	0	0	0	0	0
Available Phosphorus (%)	0	-0.656599024	-1.021389712	-0.327789968	0	-0.656599024	-1.021389712	-0.327789968
Total Phosphorus (%)	0	0	0	0	0	0	0	0
Calcium (%)	-2.153463735	-0.461281239	-0.277284924	-0.302762411	-2.153463735	-0.461281239	-0.277284924	-0.302762411
Crude Fibre (%)	0	0	0	0	0	0	0	0
Crude Fat (%)	0	0	0	0	0	0	0	0
Medication & Coccidiostat	-0.754316219	-0.111286871	-3.525368271	-0.051049716	-0.754316219	-0.111286871	-0.041368271	-0.051049716
Trace mineral and vit premix	-4.238316219	-3.595286871	-0.041368271	-3.535049716	-4.238316219	-3.595286871	-3.525368271	-3.535049716
Corn Upper Limit	0	0	-0.037657207	-0.034643328	0	0	-0.037657207	-0.034643328
Corn Lower Limit	0	0	0	0	0	0	0	0
Wheat Upper Limit	-0.211132825	0	0	0	-0.211132825	0	0	0
Wheat Lower Limit	0	0.038739879	0	0	0	0.038739879	0	0
Soybean Meal Upper Limit	-1.739836479	0	0	0	-1.739836479	0	0	0
Soybean Meal Lower Limit	0	0	0	0	0	0	0	0
Meat Meal Upper Limit	-2.133135835	0	0	0	-2.133135835	0	0	0
Meat Meal Lower Limit	0	0	0	0	0	0	0	0
Starter Feed	-0.738316219	-0.095286871	-0.025368271	-0.035049716	-0.738316219	-0.095286871	-0.025368271	-0.035049716
Starter Feed Limit (kg)	1.451813237	0.095286871	0.047962595	0.055835713	1.451813237	0.095286871	0.047962595	0.055835713
Metabolizable Energy (cal/kg)	-0.083168286	-0.083168286	-0.083168286	-0.095163092	-0.083168286	-0.083168286	-0.083168286	-0.083168286
Crude Protein (%)	0	0	0	0	0	0	0	0
Lysine (%)	-1.635941286	-1.635941286	-1.635941286	0	-1.635941286	-1.635941286	-1.635941286	-1.635941286
Methionine (%)	0	0	0	0	0	0	0	0
Methionine + Cystine (%)	-5.146754415	-5.146754415	-5.146754415	-5.248043887	-5.146754415	-5.146754415	-5.146754415	-5.146754415
Threonine (%)	-6.188108498	-6.188108498	-6.188108498	0	-6.188108498	-6.188108498	-6.188108498	-6.188108498
Tryptophan (%)	0	0	0	0	0	0	0	0
Available Phosphorus (%)	-0.656599024	-0.656599024	-0.656599024	-63.63776839	-0.656599024	-0.656599024	-0.656599024	-0.656599024
Total Phosphorus (%)	0	0	0	0	0	0	0	0
Calcium (%)	-0.461281239	-0.461281239	-0.461281239	-0.725166969	-0.461281239	-0.461281239	-0.461281239	-0.461281239
Crude Fibre (%)	0	0	0	0	0	0	0	0
Crude Fat (%)	0	0	0	0	0	0	0	0
Medication & Coccidiostat	-0.111286871	-0.111286871	-0.111286871	-0.211563448	-0.111286871	-0.111286871	-0.111286871	-0.111286871
Trace mineral and vit premix	-3.595286871	-3.595286871	-3.595286871	-3.695563448	-3.595286871	-3.595286871	-3.595286871	-3.595286871
Corn Upper Limit	0	0	0	0	0	0	0	0
Corn Lower Limit	0	0	0	0	0	0	0	0
Wheat Upper Limit	0	0	0	0	0	0	0	0
Wheat Lower Limit	0.038739879	0.038739879	0.038739879	0.022130761	0.038739879	0.038739879	0.038739879	0.038739879
Soybean Meal Upper Limit	0	0	0	0	0	0	0	0
Soybean Meal Lower Limit	0	0	0	0	0	0	0	0
Meat Meal Lower Limit	0	0	0	-2.311799001	0	0	0	0
Grower Feed	-0.095286871	0	0	0	0	0	0	0
Grower Feed Limit (kg)	0.095286871	-0.095286871	-0.095286871	-0.195563448	-0.095286871	-0.095286871	-0.095286871	-0.095286871
Meat Meal Upper Limit	0	0.095286871	0.095286871	0.357389378	0.095286871	0.095286871	0.095286871	0.095286871

Table 3 Shadow Prices For Manure Disposal Model, Scenario 1(b)

Diet. Treatmnt.	1	2	3	4	5	6	7	8
Name								
Feed	360.99	357.66	346.33	338.98	362.24	349.55	346.33	344.3
Manure	72.35	72.35	72.35	72.35	72.35	72.35	72.35	72.35
Man disposal	72.35	72.35	72.35	72.35	72.35	72.35	72.35	72.35
Storage limit	0	0	0	0	0	0	0	0
Land limit	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05
Transport limit	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86
Manure transfer	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Manure	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Man disposal	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Storage limit	0	0	0	0	0	0	0	0
Land limit	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62
Transport limit	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Manure	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Man disposal	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Storage limit	0	0	0	0	0	0	0	0
Land limit	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62
Transport limit	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure Min	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Manure	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Man disposal	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Storage limit	0	0	0	0	0	0	0	0
Land limit	0	0	0	0	0	0	0	0
Transport limit	0	0	0	0	0	0	0	0

Table 4: Shadow Prices For Manure Disposal Model, Scenario 2(a)

Diet. Treatmnt.	1	2	3	4	5	6	7	8
Name								
Feed	360.99	357.66	346.33	338.98	362.24	349.55	346.33	344.3
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure Min	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	-8.06	-8.06	-8.06	-8.06	-8.06	-8.06	-8.06	-8.06
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0

Table 5: Shadow Prices For Manure Disposal Model, Scenario 2(b)

Diet. Treatmnt.	1	2	3	4	5	6	7	8
Name								
Feed	360.99	357.66	346.33	338.98	362.24	349.55	346.33	344.3
Manure	72.35	72.35	72.35	72.35	72.35	72.35	72.35	72.35
Man disposal	72.35	72.35	72.35	72.35	72.35	72.35	72.35	72.35
Storage limit	0	0	0	0	0	0	0	0
Land limit	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05	-47.05
Transport limit	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86	-42.86
Manure transfer	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Manure	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Man disposal	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Storage limit	0	0	0	0	0	0	0	0
Land limit	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62
Transport limit	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Manure	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Man disposal	50.92	50.92	50.92	50.92	50.92	50.92	50.92	50.92
Storage limit	0	0	0	0	0	0	0	0
Land limit	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62	-25.62
Transport limit	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43	-21.43
Manure transfer	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Manure Min	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Man disposal	29.49	29.49	29.49	29.49	29.49	29.49	29.49	29.49
Storage limit	0	0	0	0	0	0	0	0
Land limit	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19	-4.19
Transport limit	0	0	0	0	0	0	0	0
Manure transfer	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Manure	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Man disposal	21.43	21.43	21.43	21.43	21.43	21.43	21.43	21.43
Storage limit	0	0	0	0	0	0	0	0
Land limit	0	0	0	0	0	0	0	0
Transport limit	0	0	0	0	0	0	0	0