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Application of the modified feed formulation to optimize economic and environmental criteria in beef cattle fattening systems with food by-products

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ABSTRACT

A simplified ration optimization method was applied to a beef cattle fattening system to evaluate the utilization of food by-products under various situations. The method was extended to reduce feed costs (*i.e.*, economic factors) and nitrogen and phosphorus excretions (*i.e.*, environmental factors) by introducing penalty coefficients of nitrogen and phosphorus contents in each ingredient of the diet in the objective function in traditional linear programming. Six regional food by-products, five commercial concentrates and two roughages were used as ingredients of the fermented total mixed ration. Constraints for the feed formulation were based mainly on nutrient requirements in the Japanese Feeding Standard for Beef Cattle. The replacement price (or acquisition cost) of food by-products was defined as the maximum price of food by-products when the feed cost with the use of food by-products was below the cost with the use of conventional concentrates. The results showed that although the replacement prices were not greatly affected by the penalty levels, they were associated with the changes in the substitution rate of food by-products for concentrates and the price of concentrates. The replacement prices were about 16 (yen/kg, as-fed basis) against the present price level of concentrates, when food by-products were substituted for a half of concentrates. Feed compositions were altered and nitrogen and phosphorus excretions were decreased by the changes of penalties, in spite of the small change in the replacement price of food by-products. Both nitrogen and phosphorus penalties greatly reduced the nitrogen and phosphorus excretions, indicating that nitrogen and phosphorus penalty coefficients should be introduced together in the objective function in order to reduce both excretions efficiently.

1. Introduction

Due to economic and environmental concerns, the feasibility of using by-products as animal feeds has been examined in many regions of both developing and developed countries. In developing countries, better utilization of non-conventional feed resources (food by-products) which do not compete with human nutrition is imperative in order to meet the projected

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DIP, degradable intake protein; DM, dry matter; EE, ether extract; MINAS, mineral accounting system; NDF, neutral detergent fiber; RR, ratio of roughage to the total feed amount on a DM basis; TDN, total digestible nutrients; TMR, total mixed ration; VA, vitamin A.

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high demand of livestock products (Maghsoud et al., 2008). In developed countries, low-cost waste management programs that involve feeding by-products from crop- and food-processing industries to farm animals have become very important in recent years (Bampidis and Robinson, 2006). As in Japan, utilization of food by-products has been strongly promoted for raising the self-sufficiency rate of feeds (Sugiura et al., 2009).

Available food by-products, or so-called Ecofeed (Economical and ecological feed resources) in Japan, include beverage wastes such as brewer's grain, distiller's grain, fruit juice pomace and tea waste, food manufacturing wastes such as soybean curd residue (tofu waste), soy sauce cake and blackstrap molasses, vegetable wastes, bakery and noodle wastes and disposals from food service industries. These food by-products usually have high energy and/or protein contents, which can provide competitive alternatives to more traditional energy or protein sources (Westendorf, 2000). Replacing imported commercial feeds with food by-products can save energy in transportation and reduce the environmental impact of burning or landfilling food wastes (Cao et al., 2009). Nonetheless, despite the vast potential of by-products as a constituent of farm animal diets, the degree of usage is dependent on the economic value of the by-products and the market prices of conventional feedstuffs (Harpster, 2000).

In recent years, environmental pollution caused by high levels of animal waste has become one of the major concerns regarding intensive animal production systems in many countries. Excess nitrogen and phosphorus excretion from feces and urine of farm animals can lead to several environmental problems. For instance, nitrogen contributes to environmental pollution in two ways, as ammonia in the air or as nitrate in soil and ground water, and a high level of phosphorus excretion leads to leakage into surface and ground waters (Tamminga, 1992). In particular, N_2O derived from nitrogen in cattle waste contributes to global warming in the process of Japanese beef production systems (Ogino et al., 2004, 2007), and the reduction in nitrogen excretion from beef production is strongly expected to meet the Kyoto Protocol in Japan.

Linear programming is certainly the most popular method for diet formulation (Brokken, 1971; Crabtree, 1982; Kikuhara et al., 2009; Tedeschi et al., 2000; Tozer, 2000). The ordinal linear programming method enables the formulation of least-cost diets that satisfy specific nutrient requirements, but it cannot consider the effects of excess nitrogen and phosphorus contents in the diets on the excretions of these substances into soil and ground water. To solve this problem, Jean dit Bailleul et al. (2001) and Pomar et al. (2007) modified the ordinal least-cost feed formulation to simultaneously minimize feed cost and excess nitrogen and phosphorus, respectively, and then applied it to the actual formulation of feed for pig production. Hirooka and Oishi (2010) used the same method to minimize feed cost and nitrogen excretion when whole crop rice silage was utilized as a feed for beef cattle feedlot production in Japan.

The objective of this study was, therefore, to evaluate the economic and environmental impact of the use of food by-products as animal feeds on the Japanese beef fattening system by using the modified least-cost feed formulation method.

2. Materials and methods

2.1. Overview of the simulation

It was assumed in this study that the beef fattening system for Japanese Black (Wagyu) steers starts from the purchase of calves with a body weight of 285 kg (initial weight) at calf markets and culminates with slaughter at a final weight of 714 kg. The fattening period was equally divided into three parts: early, middle and late. The daily gain in each period was estimated from the given average daily gain (0.7 kg/day) for the whole fattening period using the Gompertz growth curve function with the estimated mature weight (748 kg). Details of the calculation are shown in Appendix A.1. Daily nutrient requirements were calculated from the estimated daily gain and body weight in accordance with the Japanese Feeding Standard for Beef Cattle (NARO, 2008). The daily nutrients were summed up for each fattening period, and the modified least-cost feed formulation was then conducted for the constraints for nutrient requirements in each period. All simulations were carried out using the subroutine DLPRS (revised Simplex method) for linear programming implemented in the IMSL Math/Library (Visual Numerics Inc., 1994).

2.2. Feed ingredients and constrained conditions

Fig. 1 shows outline of the system of feed formulation with food by-products in this study. Six regional food by-products (brewer's grain (wet), soybean curd residue (wet), soy sauce cake (wet), blackstrap molasses, udon noodle waste and green tea waste), five commercial concentrates (corn, barley, soybean meal, wheat bran and calcium carbonate) and two roughages (hay and rice straw) were used as ingredients of the fermented total mixed ration (TMR) in this study (Table 1). Concentrate and roughage ingredients were selected as the standard imported feeds in the Japanese beef fattening system (Ogino et al., 2004), and the chemical composition of feeds was based mainly on the Standard Tables of Feed Composition in Japan (NARO, 2009). One milligram of beta-carotene was converted into 400 IU of vitamin A.

Requirements for the following nutrients on an as-fed basis were set as the constraints of the feed formulation: dry matter (DM; kg/period), crude protein (CP; kg/period), total digestible nutrients (TDN; kg/period), neutral detergent fiber (NDF; kg/period), acid detergent fiber (ADF; kg/period), calcium (Ca; kg/period), phosphorus (P; kg/period), degradable intake protein (DIP; kg/period), ether extract (EE; kg/period) and vitamin A (VA; IU/period). Margins of 10% were added to the nutrient requirements of DM, CP, TDN and DIP for safety based on the Japanese Feeding Standard for Beef Cattle (NARO, 2008). The lower bounds of the feeding amounts for NDF and ADF were set to be 160 and 100 (g/kg, DM basis), respectively.