Quest Journals
Journal of Research in Agriculture and Animal Science
Volume 8 ~ Issue 5 (2021) pp: 07-16
ISSN(Online) : 2321-9459
www.questjournals.org

Research Paper

An exploration of least-cost diets for smallholder dairy production in Zimbabwe

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ABSTRACT
Despite experiencing a significant decline in annual milk production, from a high of 260 million litres in 1991 to a low of 35 million litres in 2009, while recovering to 59 million litres in 2019 against an annual aggregate demand of 160 million litres, there are still opportunities for smallholder dairy farmers in Zimbabwe to earn more income from dairying. Feed costs, which constitute between 60 and 80 percent of the total variable costs, remain significant. The aim of the study was to analyse the cost-effectiveness of using various locally available feed formulations that are suitable for smallholder dairy farmers in Zimbabwe. Linear programming was used to analyse the nutrient profiles and cost in USD of different feed ingredients to formulate nutritious feed combinations at the lowest possible cost. The results showed that incorporating various leaf meals into dairy feed diet formulations reduced the feed costs by at least 20 percent, while still matching the nutritional composition of commercial feeds. This research recommends that smallholder dairy farmers utilize maize stover as a dairy feed ingredient at a maximum inclusion level of 31.62 percent to achieve a cost reduction of 29 percent.
KEY WORDS: *least-cost, feed, smallholder dairy farmers*

Received 28 April, 2021; Revised: 10 May, 2021; Accepted 12 May, 2021 © The author(s) 2021. Published with open access at www.questjournals.org

I. INTRODUCTION

Dairy farming is a vital part of the global food system and plays a key role in increasing farmers' revenue and access to nutritious food. As a result of the ever-growing global population, rise in per capita income, increase in consumer awareness regarding the nutritional value of dairy products and the overall changes in consumer dietary patterns, the aggregate demand for dairy products is set to increase (Kearney, 2010). In Africa, the per capita consumption of milk has increased by 86 percent from 70 kg in 1996 to 130kg in 2013 and is expected to grow a further 1-1.5 percent annually in the foreseeable future (PM Food & Dairy Consulting, 2014).

In Zimbabwe, there were more large-scale dairy farmers than smallholder dairy farmers before the Fast Track Land Reform Program (FTLRP) in 2000. Although the dairy sector remains dualistic after the FTLRP, smallholder dairy farmers now outnumber large-scale dairy farmers and are further classified as either communal, small-scale commercial or resettled farmers. Milk production is undertaken in all eight rural provinces in Zimbabwe with most smallholder dairy farmers located in Mashonaland East, Midlands, Manicaland and the Matabeleland North provinces (TranZDVC, 2019).

Overall milk output has steadily declined over the years with a peak of 260 million litres, supplied by approximately 550 registered producers, in 1991. In 2000, 117 million litres were supplied by 314 producers dropping to only 50 million litres from 175 producers in 2008 (CA17 International, 2013; MAMID, 2014). Milk output was at its lowest in 2009 at only 35 million litres. Milk output therefore plunged by 643 percent between 1991 and 2009. This drastic plunge is a culmination of national herd depletion triggered by the FTLRP, which forced many large-scale commercial dairy farmers out of production and resulted in massive destocking (Technoserve, 2014). After a slow recovery, milk output increased to 54 million litres in 2012 and 65 million litres in 2019 (CA17 International, 2013; SNV, 2016).

It is worthy to note that milk output had been declining even before the FTLRP in 2000. This is especially true in the smallholder sector, where it dropped from 2.7 million litres in 1990 to 1.5 million litres in

1998 and 1.13 million litres in 2011 (Washaya & Chifamba, 2018). As a result of the decline in milk production, both the volume and value of dairy imports heightened. Dairy production costs also increased while producer milk prices remained constant. Albeit all dairy producers experienced the cost of the production squeeze, smallholder dairy farmers were hardest pressed. According to CA17 International (2013), the decline in primary milk production has had many adverse effects on secondary processing. These include loss of jobs, higher production, processing and marketing costs and a resulting elevation in prices for consumers. Consequently, milk plants in three major cities, namely, Bulawayo, Kadoma and Mutare closed and the per capita milk consumption dropped from a peak of 25 litres in the early 1990s to the current 8 litres (Chamboko & Mwakiwa, 2016). These levels of milk consumption are generally low compared to South Africa (56 litres per capita) and Zambia (10 litres per capita) (NewsDay, 2012).

Over the years the Government of Zimbabwe (GoZ) has implemented a number of policies and supportive programs to assist the dairy industry. In 1983 the GoZ established a smallholder- targeted Dairy Development Program (DDP) with the objective to enhance milk production and marketing amongst smallholder dairy farmers as a tool for rural development (Hanyani-Mlambo, 2000). The DDP established and supported 10 smallholder dairy projects across five provinces. The Zimbabwe Association of Dairy Farmers (ZADF), formerly known as the National Association of Dairy Farmers (NADF), was restructured to address shortcomings in the dairy sector and to augment government efforts to increase milk production from smallholder dairy farmers.

Despite the financial, technical and policy support given to smallholder dairy farmers by a range of public, private, civil society actors and the donor community, milk production and productivity remained low (Hanyani-Mlambo, 2000). Current milk production levels are still far below the estimated local annual demand of 120-180 million litres which exerts considerable pressure on much needed foreign currency (SNV, 2016; Zimunda Farming Margazine, 2019). The growing demand for milk, meat and other animal products (Mapiye *et al*., 2006) is an opportunity for smallholder dairy farmers in Zimbabwe to earn more income from dairying. One of the major setbacks, however, is the rise in production cost as the increase in demand for dairy products and beef is often coupled with a higher demand for cattle feed. Feed costs constitute 60-80 percent of the total variable costs in dairying (Webster, 1993; Mudzengi *et al*., 2014; Gwiriri *et al*., 2016; Dooyum *et al*., 2018). Without cost-effective and nutritional feeding programs, the benefits of good breeding and management programs cannot be realized (Chakaredza *et al*., 2008). The purpose of this study was therefore to analyse the cost-effectiveness of various feed formulations and feed options suitable for smallholder dairy farmers in Zimbabwe.

II. LITERATURE REVIEW

Dairy producers in Zimbabwe fall into two categories, namely, large-scale commercial farming (LSCF) and smallholder farming. This segmentation is based on the scale of operations which is dependent on herd size and in turn determines the marketing channel used for milk. Smallholder dairy production on a commercial basis has existed in Zimbabwe for four decades and is thus relatively new. According to Chamboko and Mwakiwa (2016), the LSCF sector independently supplied all the milk that entered formal marketing channels in 1980. Although milk was produced in the smallholder sector, it was only for subsistence purposes. As a way of encouraging participation of previously marginalized groups in formal markets, the GoZ initiated the DDP to promote smallholder farmers' participation in commercial dairy production and marketing.

Smallholder dairy production in Zimbabwe

Smallholder commercial dairy units are predominately comprised of crossbred indigenous and exotic cattle breeds. A substantial amount of milk is also produced from indigenous non-dairy cattle breeds such as Mashona, Nguni and Tuli and a mixture of various crossbreds produced through random breeding (in a non-systematic manner). Smallholder producers have conservative herds that average at about three cows per household and the marketing channels for the milk are predominantly informal (Kagoro & Chatiza, 2012; TranZDVC, 2019). It is important to note that there are numerous smallholder milk producers in communal and resettlement areas whose production is not captured in national statistics because they are considered to be informal. According to Marecha (2009), milk production by these informal players accounts for a significant amount of the milk traded and consumed in both rural and urban areas through informal marketing channels.

Marius *et al*. (2010) found that smallholder dairy farming in Zimbabwe is characterised using inappropriate cattle breeds, inadequate managerial skills and practices, shortage of appropriate feeds, and poor disease prevention and control measures. The study also found that farmers prefer crossbreds compared to purebreds of both indigenous and exotic breeds. The selection criteria were based on milk yield and animal growth rate. These findings are to be expected given that the farmers would want to balance adaptability to local climatic and environmental conditions and the need for better performance in terms of milk and meat yield. The generally low genetic potential for milk production in indigenous breeds (even under optimal conditions and adequate feeding regimes), have prompted the need for crossbreeding with exotic breeds for improved milk production. However, the viability and sustainably of smallholder dairy production in Zimbabwe continues to be threatened by the high cost of production driven mainly by the feed component (Kagoro & Chatiza, 2012; Sukume & Maleni, 2012; Technoserve, 2014; TranZDVC, 2019).

Dairy diets for improved milk yields

Improvement in grain crop production in Zimbabwe in the 1930s resulted in the expansion of the dairy industry (National Association of Dairy Farmers of Zimbabwe, 1987). Dairy cattle, like any other ruminant animal, primarily depends on forages or fodder. However, grazing systems on the smallholder sector offer limited potential for dairy production and animals confront severe nutritional stresses during dry periods when the rangelands are both low in nutritional value and in short supply (Ngongoni & Manyuchi, 1993). During such periods, the animals' body condition may deteriorate resulting in low milk yields, low conception rates and poverty deaths that culminate into high economic losses. Water scarcity between December and June is another contributing factor. Animals travel far distances in search of water which can sometimes lead to human-animal conflicts. The lack of adequate pastures, water scarcity and human-animal conflicts are common not only in Zimbabwe but also in other African countries. Supplementary provision for food and water for the animals is therefore critical during lean periods.

Feeds for dairy animals are categorised into forages (improved and non-improved), cereals and their by-products, legumes and their by-products, additives, commercially purchased supplements and total mixed rations (Topps & Oliver, 1993). Cereals are the principal source of energy in concentrates for ruminants (McDonald *et al*., 2010). Farmers with irrigation grow improved grasses and legumes such as midmar rye grass, bana grass, kikuyu or star grass, silver leaf desmodium, velvet bean, lucerne and leucaena to feed the dairy animals (Topps & Oliver, 1993). Studies on forage legumes have indicated that commercially purchased dairy concentrates can successfully be replaced by cowpea and velvet bean (Murungweni *et al.*, 2004).

Forages can be conserved for supplementation feeding during the dry season. The roughage component of a dairy feed, whose importance is often taken for granted, is usually the cheapest feed ingredient. Roughages, also referred to as fodder or forages, are a source of basal fibre. This is vital for rumen function (microbial fermentation) and provides the "scratch factor" for rumen motility as well as the "gut fill" (McDonalds *et al*., 2010). Roughage is the predominant energy source for dairy cattle, however, during the rainy season some forages such as lucerne, kikuyu and rye grass or good natural veld grass (> 8 percent crude protein) can provide enough protein for maintenance.

Except for the above mentioned, roughages generally have low energy and protein levels, typical 6 MJ ME/ kg dry matter and 3 percent crude protein (CP) but have high fibre levels of 25 - 55 percent (Mutetwa, 2004). The protein is lowly degradable (0.50). Nevertheless, the nutritive value of most roughage can be improved using ammonia, molasses and urea or ensiling. The response to treatment is higher for material of low initial digestibility. Chopping can also be done to improve roughage intake. The ideal length for milled / chopped grass hays is 3 - 5 cm (PTC^+, 2010).

Most farmers in Zimbabwe depend on rain fed agriculture in which they execute summer cropping of cereals and oilseeds such as maize, sorghum, millet, soybean, groundnut, cotton and sunflower (Ngongoni *et al*., 2007). The cereals are high in energy whilst the oilseeds' by-products are high in protein. Simple on-farm feed formulations are carried out using cereals and oilseeds to boost milk production. Urea, ammonium-salts, and uric acid (poultry droppings) are also used as cheap sources of non-protein nitrogen (NPN) (McDonalds *et al*., 2010).

Nutritive additives are necessary in feed formulations to prevent metabolic disorders. In complete feeds, additives are generally considered to be indispensable. Examples of these include but are not limited to vitamins, minerals and essential amino acids (McDonalds *et al.*, 2010).

Ruminant feeds are mostly balanced for protein and energy. Vitamins and minerals are also incorporated into the feed in small quantities as premixes. Data on the nutrient requirements of dairy cows varying in weights and milk production are given in Table 1.

Table 1. Nutrient needs for maintenance and milk production of different live masses

Live mass (kg)	Milk (kg)	Dry matter (kg)	ME (MJ)	DCP (k)
350	10	9.8	89	765
	20	10.8	138	1,285
	30	11.8	138	1,805
400	10	11.0	94	780
	20	12.0	143	1,300
	30	13.0	193	1,820

450	10	12.3	98	790
	20	13.3	147	1,300
	30	14.3	197	1,840
500	10	13.5	103	800
	20	14.5	152	1,320
	30	15.5	202	1,840
550	10	14.8	108	805
	20	15.8	157	1,325
	30	16.8	207	1,845

Source: Adapted from Topps & Oliver, 1993

According to Dunham (1989), it is recommended that a cow be fed 0.4 kg of dairy meal concentrate per litre of milk produced for yields below 15 kg per day. This assumes that the forage part of their diet has provided for the maintenance requirements as well as about 5 kg per day of milk production. For example: A lactating cow with a live weight of 350 kg, producing 10 litres of milk per day would require 89 MJ ME and 765 g DCP (Table 1). Furthermore, based on the 0.4 kg dairy meal concentrate per litre of milk produced, the lactating cow should be given 4 kg of dairy meal concentrate per day. The dairy meal concentrate fraction would therefore supply 44 MJ ME and 360 g DCP. The deficit in normal feeding programs should be satisfied by the forage component of their diet.

A critique of feed formulation methods

The following livestock feed formulation methods are discussed below briefly with the objective of selecting an appropriate method from the literature that provides a desirable feed ration at known cost; Pearson square method, simultaneous equation method, two-by-two matrix method, Imami method and linear programming method.

Pearson Square Method

The Pearson square method has been used for many years because of its simplicity and usefulness. It can be used to balance the nutritional requirements for an animal for a specific nutrient which may be crude protein or total digestible nutrients (TDN), amino acids, minerals, or vitamins. Olusayo *et al.* (2013), argue that its disadvantages include; its usability for only two requirements at the same time and the lack of consideration given to other nutritive requirements such as vitamins and minerals. While it is agreed that this box method of balancing rations is simple and has been widely used in formulating livestock feed rations (Toress-Rojo, 2001; Alexander *et al*., 2006), it can be argued from an economic perspective that the model has no capability to optimize costs.

Simultaneous Equation Method

The simultaneous equation and matrices method, also known as the trial-and-error method, is an alternative method to the Pearson square method. It is popularly used for formulating poultry rations. As its secondary name suggests, the trial-and-error method, the formulation is manipulated until the nutrient requirements of the animals are attained (Ghosh *et al*., 2012). The ration formulations using this method can be done manually on paper or with the aid of a computer program such as Microsoft Excel. Ghosh *et al.* (2012), describe this method as laborious and time consuming. This paper concurs with the point and adds that the method does not take the cost of the feed ingredients into account.

Two-By-Two Matrix Method

This method is not very different from the simultaneous equation and matrices method except that it solves two nutrients requirement using two different feed ingredients. A 2 x 2 matrix is formed, and a set or series of equations are solved to determine the solution to the problem (Ghosh *et al*., 2012).

Imami Method

Gosh *et al.* (2012) describe this method as an educational way of balancing simple rations by using a common calculator with a high accuracy for farmers who do not have access to a computer. The major limitation of the Imami method and the two-by-two matrix method is that the resultant rations are computed independent of the price of the feed ingredients. Although the livestock feed formulation methods have been used in different circumstances for their advantages, their major and common weakness is that they overlook the cost of the feed ingredients in their solutions.

Linear programming method

The linear programming model, originating from the army, is also known as the feed cost computerized feed formulation method (Olusayo *et al*., 2013). Linear programming as a mathematical tool was first introduced by George Dantzig and his associate in 1947 while they were working for the United States of America air force (Ghosh *et al*., 2012). The model came into use during the 1960's in feed mixing plants and animal farm enterprises for ration formulation problems. Since then, the concepts have been used extensively for decision making under constrained optimization of costs in feed economics, microeconomics, and management among other fields. Linear programming has been widely used to model feeding problems for cattle (Chakeredza *et al*., 2008), other livestock classes and for fish (Porchelvi *et al*., 2018). The common objective in formulating the feed mix is to minimize cost while still providing adequate nutrients to meet the needs of the farm animal in question. (Chapell, 1974).

The method or model has several advantages over the above-mentioned methods. Olusayo *et al*. (2013) noted the following advantages for using the linear programming method.

(i) It is a scientific problem-solving approach that better describes the problem at hand to be meticulously analysed to ascertain a solution.

(ii) It allows the decision maker to make more informed decisions that accurately reflect all the limitations present in the system that influence its optimality. If it becomes necessary to deviate from the optimal path, linear programming can easily be used to evaluate the associated costs or penalty. It guarantees that the optimal solution is always found if the model is formulated correctly.

(iii) The linear programming method ensures that all possible solutions are generated, out of which the optimal solution is selected.

(iv) The method is not rigid but rather more flexible.

In addition to these advantages, the linear programming method is unique because it enables users to formulate least cost diets. Albeit the linear programming method being practical, flexible, using a scientific approach in solving problems among other merits, it does not go without criticism. The issues raised against using linear programming in formulating feed diets include.

(i) *Ingredient variability*. Nutrient levels of feed ingredients are unstable and fluctuate (Chapell, 1974). Forages make up a principle amount of the feed diet for which the nutrient content can vary significantly (Tozer, 2000).

(ii) *Price variability*. Prices of feed ingredients are not constant- (Rahman *et al.,* 2010).

(iii) *Linear relationship*. The model assumes a linear relation in solving feed mix problems, yet some problems are non-linear and may require other forms of equations.

(iv) *Constant value of objective and constraint equations*. Olusayo *et al.* (2013) argue that before a linear programming technique can be applied to any feed mix problem, the values or coefficients of the objective and constraint functions must be completely known and be constant over a period. They add that when the values change during the period of study, the method loses its effectiveness and may fail to provide an optimal solution to the problem.

(v) *Multiplicity of goal*. The linear programming method has only two objectives viz., to formulate feed diets at low costs, however, smallholder farmers, just like any other entrepreneurs, have a multiplicity of goals. Although, other feed formulation methods that can solve a multiplicity of problems and hence solve several goals at once are preferred, taking a stepwise approach in problem solving cannot be ruled out for its simplicity.

Based on the above weaknesses of the linear programming model, the following methods have been proposed or developed; neuro-fuzzy animal feed formulation (Olusayo *et al*., 2013), goal programming, multi-objective goal programming, multi-objective fractional programming, nonlinear programming, chance constrained programming, quadratic programming, and risk formulation (Ghosh *et al*., 2012) among others.

Despite the above-mentioned demerits, this paper opted to use linear programming because of its strength in formulating least cost feed diets, which has been identified as the objective of this study. The cost of feed formulations can account for up to 80 percent of the variable costs in dairying (TranZDVC, 2019). Farmers can therefore use their comparative advantage to incorporate forage, which sometimes grows abundantly and is naturally occurring, in their feed formulations in optimal quantities to reduce feed costs whilst still maintaining adequate nutritional value.

III. THEORY

The performance of smallholder dairy production and marketing in Zimbabwe can be understood from a producer theory or theory of the firm's perspective. According to the theory, the major objective for operators of any enterprise is to maximize economic profits. Therefore, a profit-maximizing enterprise chooses both its inputs and its outputs with the sole goal of achieving maximum economic profit. In other words, the enterprise will seek to maximize the difference between total revenue and total economic costs. It is well known that profit maximization is predicated upon satisfaction of the cost minimization assumption (Moschini & Hennessy, 2008). Profit maximization is therefore a crucial expected utility assumption. The question, however, is whether cost minimization continues to hold under risk and uncertainty when the objective is maximization of the expected utility (profit). The answer is yes, provided that "cost-effectiveness" is properly and suitably defined.

The profit maximization problem can be split into two parts. Firstly, there is the problem of how to minimize the costs of producing any given level of output and secondly, how to choose the most profitable level of output. However, traditionally the main objective of dairying among smallholder farmers in Zimbabwe is not to maximize profits. It has been practiced for reasons other than profit making which include; feeding the family, to produce manure to support crop production, to provide dairy animals as insurance for financing emergency cash needs and for social status (Bebe *et al*., 2003). Only after these needs are met can surplus milk be sold to nearby markets (Washaya & Chifamba, 2018). In this paper, we will deal with feed cost problems by combining the cost minimization approach and feed formulation methodologies.

IV. OVERVIEW OF METHODOLOGY

A desktop study consisting of 47 literature items related to animal feed formulations was reviewed. The nutritional composition of the feed ingredients was derived from Topps and Oliver (1993) and Mpofu *et al*. (2006). The corresponding prices were derived from the Zimbabwe Farmers Union (ZFU) Market Guide (March 2020) and converted to USD using the Reserve Bank of Zimbabwe's listed (RBZ) exchange rates.

The value of maize stover was derived from the author's interactions with smallholder farmers on dryland in Natural Regions III-IV of Zimbabwe. Five dairy meals with 16 percent CP and 11 MJ/kg metabolizable energy were formulated using different leaf meals, namely, giant rhodes, napier and cenchrus grasses as well as alfalfa and maize stover. The diets approximate to the same nutritional composition of commercial dairy meal concentrate to meet the requirements of a dairy cow during mid-lactation. Microsoft excel least cost computations (linear programming) were used to devise feed formulations and calculate the total cost of the optimal diet. The cost of producing each dairy ration was compared to the commercial dairy meals.

V. MODEL SPECIFICATION- LINEAR PROGRAMMING

The basic objective function for formulating feed mix using linear programming is to minimise cost. The nutritional requirements as per the demand of the animal are introduced into the model as constraints. The linear programming model for feed formulation has the following structure with 'n' decision variables and 'm' constraints:

Let:

$Z \triangleq$ The total cost (in USD) of the ration

$C_j \triangleq$ The cost (in USD) per kg of dry matter for ingredient j, where $j = \{1, ..., n\}$

$X_j \triangleq$ The quantity of ingredient j,where $j = \{1, ..., n\}$

$b_i \triangleq$ The required amount of nutrient i in the ration ,where $i = \{1, ..., m\}$

$Q_{i,j} \triangleq$ The quantity of nutrient i in ingredient j ,where $i = \{1, ..., m\}$ and $j = \{1, ..., n\}$

$$Min \quad Z = \sum_{j=1}^{n} X_j C_j$$

Subject to:

$$\sum_{j=1}^{n} Q_{i,j} X_j \quad (\leq, \geq, =) \quad b_i \quad \forall \quad i \in \{1, ..., m\}$$

$$X_j \geq 0 \quad \forall \quad j \in \{1, ..., n\}$$

Minimize $Z = \sum CjXj$ where j= 1,…, n

Subject to $\sum_{j=1}^{n} Qij\ Xj$ (≤, =, ≥) b_i for i = 1, …, m

and Xj ≥ 0

Where Z is the total cost of the ration

Cj is the cost per kg of dry matter of j^{th} ingredients, are coefficients of decision variables in the objective function;

Xj is the quantity of ingredient j
Qij is the quantity of the i^{th} nutrient in ingredient j
b_i is the required amount of nutrient i in the ration

According to Dent and Casey (1967), the basic assumptions for the linear programing model are.
(i) The single objective minimization of diet cost is the mathematical function of the decision variables.
(ii) The decision variable is the amount of available ingredients that constitute the diet
(iii) The nutritional requirements are convertible to mathematical functions which constrain the model.
(iv) The optimum diet is the one that minimizes the single specified objective, the least cost, without any violation of the constraints imposed.

The model was solved in Microsoft Excel using a "SOLVER" function by following the five steps laid down by Chakeredza *et al.* (2008). The results are found in table 2 below.

Table 2. Nutrient content and prices of common feeds in Zimbabwe

Element	DM (%)	ME (MJ/kg)	CP (%)	Ca (%)	P (%)	Cost (US$/kg)
Forage & legumes						
Lucerne (green)	18.2	8.8	25.3	1.60	0.25	0.20
Napier	14.5	8.0	10.3	0.36	0.32	0.20
Giant Rhodes grass	18.7	9.3	13.7	0.51	0.32	0.20
Acacia pods	99.4	11.32	14.62	0.98	0.26	0.10
Dychrostachys cinera pods	97.49	10.2	11.92	0.64	0.14	0.10
Piliostigma spp pods	96.65	7.67	6.71	0.27	0.11	0.10
Velvet beans	18.5	8.5	24.6	0.61	0.12	0.50
Leucaena	18.3	8.8	26.91	1.2	0.13	0.10
Star grass	17.0	9.8	20.8	0.49	0.31	0.20
Cenchrus grasses	14.2	10.4	13.7	0.50	0.29	0.20
Alfalfa	13.5	8.3	10.1	1.78	10.4	0.20
Maize stover	90	8.0	4.0			0.13
Silages						
Maize	40.0	10.5	8.1	0.27	0.20	
Sorghum	26.2	8.4	7.8	0.30	0.20	
Grains						
Maize grain (white) crush	87.3	13.8	10.2	-	0.40	0.39
Sorghum grain crush	90.0	12.6	11.8	0.04	0.33	0.41
Pearl Millet grain crush	88	11.0	9.71			0.41
Finger millet grain crush	89	9.0	10.0			0.41
Wheat feed crush	88	12.0	9.5			0.49
Oilseeds & meals						
Cotton seed cake	94.4	11.1	37.9	0.20	0.30	0.20
Soybean meal	88.6	10.5	44.0	0.25	0.34	0.23
Blood meal	89.6	9.0	93.7	0.28	-	
Meat & bone meal	96.0	9.7	59.0	11.20	-	
Mineral Supplements						
Dicalcium phosphate	-	-	-	22.0	18.0	
Monocalcalcium phosphate	-	-	-	16.0	20.0	
Limestone flour	-	-	-	37.0	-	
Vitamin-mineral premix						0.50
Liquid ingredients						
Molasses			4	0.67	0.05	0.35

Sources: Mpofu et al (2006), Topps & Oliver (1993), ZFU Market Guide (2020)

VI. RESULTS AND DISCUSSION

Table 2 presents nutrient contents for common dairy feed regimes used in Zimbabwe and their current prices/costs per kg. The costs for common feed components of dairy diets generally range from US$0.10 to US$0.50 per kg. These costs are almost comparable to those in the SADC region, where they range from $0.11 to $0.50 (Topps & Oliver, 1993). In smallholder dairy farming, the practice is generally aimed at adopting the least cost approach to on-farm feed formulation using locally available resources.

The nutritional requirements for milk production by a dairy cow are dependent on its milk yield potential, the milk quality or composition as well as the availability and quality of roughage (McDonalds *et al*., 2010; PTC+, 2010). In this paper, different dairy meal concentrates of 16 percent CP and 11 MJ ME/kg were formulated using Excel spread sheet computations (Table 3). The diets approximate to the same nutritional composition of commercial dairy meal concentrates given to mid-lactation dairy cows (Dunham, 1989). The vitamin mineral pre-mix was incorporated at 1.4 percent.

The formulated feeds, including the "Control" are generally a mimic of the bought-in dairy meal concentrates. The inclusion levels for the leaf meals range between 31.62 percent for maize stover to 48.72 percent for Giant Rhodes grass.

Table 3. Least-cost diet formulation derived using the Excel spreadsheet

	Leaf meal (% composition)					
Raw material	**Control**	**Giant Rhodes**	**Napier grass**	**Cenchrus grass**	**Alfalfa**	**Maize Stover**
Maize crush	77.88	34.53	42.21	33.48	40.17	38.35
Cotton seed cake	20.72	15.35	21.41	15.20	21.67	28.63
Leaf meal		48.72	34.98	49.92	36.76	31.62
Vitamin-mineral premix	1.4	1.40	1.40	1.40	1.40	1.40
Total	100	100	100	100	100	100
Crude Protein %	16.00	16.00	16.00	16.00	16.00	16.00
ME (MJ/kg)	13.05	11.00	11.00	11.00	11.00	11.00
Cost (US$/kg)	**0.35**	**0.27**	**0.28**	**0.27**	**0.28**	**0.25**

Results have shown an inverse relationship between the inclusion of a leaf meal and cotton seed cake in the diet. The inclusion of a leaf meal in the diet reduces the levels of cottonseed meal and maize grain crush needed. Inclusion of Giant Rhodes and cenchrus grasses reduced the costs of formulating the two dairy meals from $0.35 per kg to $0.27 per kg, while the inclusion of Napier grass and Alfalfa reduced the costs of formulating the two dairy meals from $0.35 per kg to $0.28 per kg. Inclusion of maize stover in the feed formulation reduced the cost from $0.35 per kg to $0.25 per kg. Based on these findings, dairy feed diet formulation using maize crush, cotton seed cake, maize stover and vitamin-mineral premix as ingredients, reduced the cost of feed by 29 percent. Substituting maize stover with either Giant Rhodes or Cenchrus grass reduced the cost of feed by 23 percent, while substituting maize stover with either Napier grass or Alfalfa reduced the cost of feed by 20 percent. Overall, the inclusion of leaf meals in the feed formulation reduces the feed cost by a minimum of 20 percent. Results are consistent with findings by Chakeredza *et al.* (2008).

The study has shown that the most cost-effective dairy meal formulation comprises of 38.35 percent crushed maize grain, 28.63 percent cotton seed cake, 31.62 percent maize stover and 1.4 percent vitamin-mineral premix. The findings are concurrent with research done by Gusha *et al.* (2013) who declare that utilization of low cost and readily available feed resources which meet the requirements for milk production can optimize farm income.

In smallholder dairy farming systems, feed costs account for 60 - 80 percent of the production costs, which limits economic viability of dairy enterprises (Webster, 1993; Mudzengi *et al*., 2014; Gwiriri *et al*., 2016; Dooyum *et al*., 2018). Therefore, in this paper, the dairy meals were formulated based on locally available feed ingredients that are accessible to the smallholder dairy farmer at low costs. Other studies have indicated that commercial dairy concentrates can successfully be replaced by cowpea and velvet bean (Murungweni *et al.*, 2004). This study proposes the inclusion of maize stover in dairy meal formulation as it is convenient for the smallholder farming system in Zimbabwe given that it is characterized by crop-livestock integration with maize as the staple food crop. In addition, feed and water availability are constrained between June and December. This means that cost effective feed conservation and formulations to reduce dry season feed costs are essential. Thus, as farmers are growing maize for home consumption, they must also retain, store and use the stover in low-cost formulation of dairy meals. From the authors' experience in smallholder agriculture, the amount of maize grain harvested almost equates to the amount of maize stover generated. Thus, farmers' efforts to increase their maize productivity has a multiplier effect on their overall farm productivity.

VII. CONCLUSION AND RECOMMENDATIONS

The study has shown that formulating a dairy meal with locally available feed ingredients is cost-effective, reducing the feed costs by a minimum of 20 percent. A feed formulation consisting of cotton seed cake at $0.20 per kg, maize grain crush at an average price of $0.39 per kg, maize stover at an average price of $0.13 per kg and a vitamin-mineral premix at an average price of $0.50 per kg was found to be the most cost-effective diet. The inclusion of maize stover in the formulations reduced the feed cost by 29 percent and is convenient for smallholder dairy farming, which is characterized by rain-fed, crop-livestock integrated farming systems with maize grain as the staple food crop. Substituting maize stover with either Giant Rhodes or Cenchrus grasses reduced the cost of feed by 23 percent, while substituting maize stover with either Napier grass or Alfalfa reduced the cost of feed by 20 percent. The inclusion of leaf meals in dairy diets decreases the feed cost by at least 20 percent. It is strongly recommended for programs and project interventions that are supporting smallholder dairy farmers operating in similar or related climatic, economic and social environments to encourage them in identifying and mobilizing locally available feed resource ingredients for use in formulating least-cost dairy feed diets. This will not only increase farmers' access to nutritious food as milk production increases, but will also result in more dispensable net incomes generated from dairying which will make them more resilient to shocks and stressors. For future studies, a cost-benefit analysis of feed formulations using crop residues such as urea treatment of stover or ammonisation of maize stover using Mabiko K is recommended.

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