DEVELOPMENT OF MULTI-OBJECTIVE RATION FORMULATION PROGRAM TO OPTIMISE FEED MILLERS, DAIRY PRODUCERS AND POLICY REGULATORY GOALS

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A thesis submitted to the Graduate School in partial fulfilment for the requirements of the award of Doctor of Philosophy in Animal Science of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not wholly, or in part, been presented for award of a degree or diploma in this or any other university known to me.

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Recommendation

This thesis is the candidate's original work and has been prepared with our guidance and assistance. It is submitted with our approval as the official university supervisors.

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DEDICATION

This work is dedicated:

TO THE MEMORY OF MY LATE FATHER

(1915-1994)

"... Commit your works to the LORD, and your thoughts will be established" -

Proverbs 16:3

and

My mother Tabitha Kanyilu, my wife Margaret and our three great children, Joseph Mutua, Tabitha Kanyilu, and Dorine Ndinda as well as all my siblings for their continued support, prayers, and encouragements. They remained a source of inspiration even when the going promised little hope.

ABSTRACT

Dairy ration formulation in Kenya is currently based on the singular objective of least cost (LCF) that only considers cost to the economic advantage of feed millers. The interest of dairy producers is milk profit above feed costs while regulatory authorities are interested in feed quality standards and environmental health. Industry stakeholder interests on feed processing and utilisation and critical feed formulation goals present challenges to sustainable dairy production. To better address the existing challenges in the feed industry with a view to offering a solution, the current study was implemented in two stages. Part I embarked on a survey to determine the relationship between dairy ration formulation and utilisation interests of feed industry actors and the critical feed formulation goals. Part II focused on the development of a multi-objective feed formulation (MOF) program that incorporated survey results to optimise the critical formulation goals step-wise, which was validated using feeding trials that compared economic, production, and environmental performance of LCF and MOF diets. Results revealed that there was a statistically significant difference in the interests on feed processing and use on: feed cost, H (3), (N = 78) = 52.24, p = 0.00; milk production, H (3), (N = 78) = 25.97, p = 0.00; feed quality, H (3), (N = 78) = 42.46, p = 0 .00 and nutrient pollution H (3), (N = 78) = 16.49, p = 0.001; between the stakeholder groups, representing an underlying conflict in dairy feed manufacturing decision-making process. The MoF program was able to integrate the four critical feed formulation goals step-wise and process a multiple objective dairy ration formula that accounts for the unit feed cost, projects daily milk profit margins, calculates feed quality levels and the potential unit and gross P-manure environmental pollution. Compared to feeding LCF diets, cows fed on MOF diets had higher ($p < 0.05$) milk yield (0.04 kg/cow/day) and lower manure-P excretion (1.66 vs 1.71 g/kg DM manure), but higher ($p < 0.05$) milk P content (0.16 vs 0.13 g/cow/day). Milk quality was higher ($P < 0.01$) in fat content (2.60 vs 1.50 g/kg) but lower in protein content (0.22 vs 0.24 g/cow/day) while mean body weight change were comparable (430.60 vs 425.70 kg) for both diets; demonstrating the advantages of using MOF over LCF formulated diets. Relationships between industry actor interests on critical feed formulation goals; and results from feeding validation trials are important to livestock development partners in their effort to formulate appropriate policies for practical feed manufacturing to support sustainable dairy entrepreneurship.

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LIST OF ABBREVIATIONS AND ACRONYMS

CAFO	Concentrated Animal Feeding Operations
CAST	Council of Agricultural Science and Technology
DFM	Dairy Feed Manufacturing
DHA	Daily Herbage Allowance
DLP	Director of Livestock Production
DLPO	District Livestock Production Officer
FCM	Fat Corrected Milk
IFAD	International Fund for Agricultural Development
IMT	Iterative Modelling Technique
IT	Information Technology
KALRO	Kenya Agriculture and Livestock Research Organization
KEBS	Kenya Bureau of Standards
Kg	Kilogram
LBW	Live Body Weight
LCA	Least Cost Approach
LCF	Least Cost Feed concentrate
LP	Linear Programming
MOF	Multi-Objective Feed concentrate
MoLD	Ministry of Livestock Development
MoF-DE (2010)	Multi-Objective Formulation: Dairy Edition for 2010
MS	Microsoft
NEMA	National Environment Management Authority
NIRS	Near Infrared Spectroscopy
NRC	National Research Council
OOD	Object Oriented Design
OOP	Object Oriented Programming
SAP	Structural Adjustment Programme
SDCP	Smallholder Dairy Commercialisation Programme
SDPM	System Development Process Model
SQL	Structured Query Language
TMR	Total Mixed Rations

CHAPTER ONE
GENERAL INTRODUCTION

1.1 Background information

Kenya is a leading dairy producer in Eastern Africa and has the highest per capita milk consumption estimated at 110 kg, which is about four times higher than the average of 25 kg for Sub-Saharan Africa (KNDMP, 2010). The consumption is attributed to the large population of dairy cattle estimated at 3.5 million heads, annually producing 3.8 billion litres of milk of which 66% is marketed (MoLFD, 2006a; 2009). Kenya's dairy sub sector contributes an estimated 4% to the GDP, supports over one million smallholder dairy households, and directly generates about 365,000 waged jobs and a further 500,000 jobs in dairy support services (MoLFD, 2006b; MoLD, 2008a).

Kenya's dairy production is predominantly based on pastures and crop residues under production systems that experience marked seasonality in feed quality and quantity supply. Good quality pastures and crop residues only support modest levels of milk production, estimated between 7 and 12 kg per cow per day (MoLD, 1995; Mbugua, 1999; MoLD, 2008a). Attaining milk yields above these levels requires the use of dietary supplementation to increase nutrient intake. Supplements for dairy cows are formulated to meet specific nutrient requirements of an animal of known production and physiological status. Commercial dairy concentrates are expensive and of variable nutritional quality (MoLD, 2006b). In Kenya, the quality standards specified for commercial dairy meals are minimum crude protein (CP) of 16-20%, maximum crude fibre (CF) of 12%, minimum calcium (Ca) of 0.7% and phosphorous (P) of 0.5% offered with adequate levels of vitamins A and D as well as trace elements (KEBS, 2009). The P level specified is in excess by 0.18% above the recommended nutrient requirement (NRC, 1989; 2001), which presents a potential threat to environmental pollution.

Millers implement the regulated specifications for dairy rations using Linear Programming (LP), which selects those combinations of ingredients that minimise feed cost within imposed constraints (Tozer and Stokes, 2001). The LP only optimises one objective of the least cost, by maximising the use of roughages while minimising the amounts of concentrates for the supply of deficient nutrients to meet the daily requirements of the target animal. The ration formulation approach has been criticised for rigidly imposing the singular objective function (Rehman and Romero, 1984; Lara 1993) because of the many limitations experienced when formulating rations in practice.

Additionally, milk market prices in Kenya are seasonal. During the rainy season when good quality pastures are plenty and milk yields are high, dairy producers fetch low milk prices. On the contrary, during the dry season when good quality pastures are scarce and milk yields are low, dairy producers fetch high milk prices. Dairy producers intending to benefit from the high milk prices during the dry season could supplement their cows with good quality dairy meal; provided the profit margins remain favourable. However, chances of environmental P-manure pollution exist since available formulation programs do not address minimum P-levels in dairy rations as a critical formulation goal. Consequently, the seasonality of market milk prices and the growing environmental pollution concerns demand for decisions on formulation and utilisation of dairy rations that satisfy the multiple objectives of the feed millers and dairy producers while adhering to regulatory requirements on the quality standards as well as the restriction on excess nutrients polluting the environment. Kenya being a signatory to the Millennium Development Goals (MDG), has obligations to attaining the MDG number seven which seeks to minimise excessive pollutant nutrients for environmental sustainability as captured in the national development blueprint, the vision 2030 (Kenya Vision, 2030) as well as the Kenya Constitution of 2010. Therefore, the aim of the current study was to provide a decision support software tool that attempts to integrate economic, production and policy objectives of all dairy feed industry players collectively.

1.2 Statement of the problem

Dairy feed formulation is currently based on the singular objective of LCF that considers cost as the only critical goal to feed formulation and yet industry actors' interests are many and diverse. Additional, critical dairy feed formulation goals include milk production, feed quality standards and environmental nutrient pollution. Balancing industry actor interests on feed processing and utilisation with the critical feed formulation goals satisfactorily present challenges to sustainable dairy production under the LCF methodology. While least cost formulation approach satisfies millers' interests of minimising feed costs and maximising manufacturing profits, it does not adequately incorporate the objective of milk production as a concern for dairy producers intending to maximise income above the market price of feed at the prevailing milk prices; and the policy regulatory objective of limiting the excretion of excessive pollutant nutrients from dairy enterprises into the environment. Such diverse stakeholder interests and multi-dimensional goals in dairy ration planning, formulation, processing and utilisation necessitates the application of a multiple objectives (MoF) approach to dairy feed formulation that potentially optimises least cost of ingredients with milk yield and profit as well as minimum excretion of pollutant nutrients into the environment step-wise. It was the aim of the current study to develop a multi-objective ration formulation program that seeks to optimize the multi-dimensional interests and goals of industry stakeholders.

1.3 Research objectives

1.3.1 General objectives

The overall objective of the study was to contribute to sustainable dairy productivity.

1.3.2 Specific objectives

The specific objectives were to:

i. Determine the relationship in the opinion on feed processing and use among feed millers, dairy producers, and policy regulators?

ii. Develop a multi-objective feed formulation program that optimises the multiple objectives of least cost, feed quality, profitable milk production and minimum nutrient excretion.

iii. Compare milk yield, nutrient excretion and cost from dairy rations formulated with least cost and multi-objective approaches.

1.4 Research questions

The study aimed to answer the following research questions:

i. Is there any difference in the interest in feed processing and use among feed industry actor groups?

ii. Does multi-objective feed formulation approach produce dairy rations that are more profitable and with less nutrient excretions than the least cost formulated dairy rations?

iii. Is the milk yield and milk quality higher, and nutrient excretion and feed cost lower when animals are fed dairy rations from least cost formulation than when fed rations from multi-objective formulation?

1.5 Justification of the study

The current singular approach to feed manufacturing is limited in optimising business, production and policy challenges of dairy farming in the 21st century. Firstly, the singular objective of minimising ingredients cost only addresses the millers' business objectives. Secondly, the approach does not provide for options to adjust feeding to animal's production potential for maximum milk yield and profits. Thirdly, the formulation approach does not impose the constraint of minimum nutrient excretion as a critical goal in compliance with excess pollutant nutrients excretion into the environment from dairy production systems. Although some new versions of LP ration formulation programs have been equipped with an auto-balancing optimiser that finds the least cost combination of ingredients within set maximum profit constraints. However, it is often discouraging when the optimisation process does not yield a solution as defined. To address the limitations of least-cost feed formulation methodology, the current study invested in the development of a multi-objective ration formulation program that seeks to optimize economic, production, environmental and policy issues step-wise. The software product is expected to serve as a decision-making tool among feed industry players as they plan, procure, process and manufacture feedstuffs and feed products for the a sustainable dairy entrepreneurship.

CHAPTER TWO
LITERATURE REVIEW

2.1 Feed industry in Kenya

There are about 120 operational feed millers in Kenya, with high concentration (66%) in Nairobi, (33%) in the Rift Valley, moderate concentration (18.3%) in Central and less concentration (10.8%) in Coast, Eastern and Nyanza regions. Figure 1 demonstrates a general increase in the total traded livestock feeds and dairy feeds from 1991 to 2009 though the total production estimated at 466,151Metric Tonnes (MT) was below the installed capacity of approximately 600,000 MT. According to Ministry of Livestock Development annual report (MoLD, 2010), the highest percentage is represented by poultry feeds (56%), followed by cattle feeds (32%), pigs (9%) and other types (3%). Feed ingredients are mainly imported, except energy sources from cereals and cereal-by products. Protein sources particularly sunflower and cotton seed cakes are imported from the Eastern Africa region. Premixes are sourced from Israel, Netherlands, and Switzerland (MoLFD, 2006a).

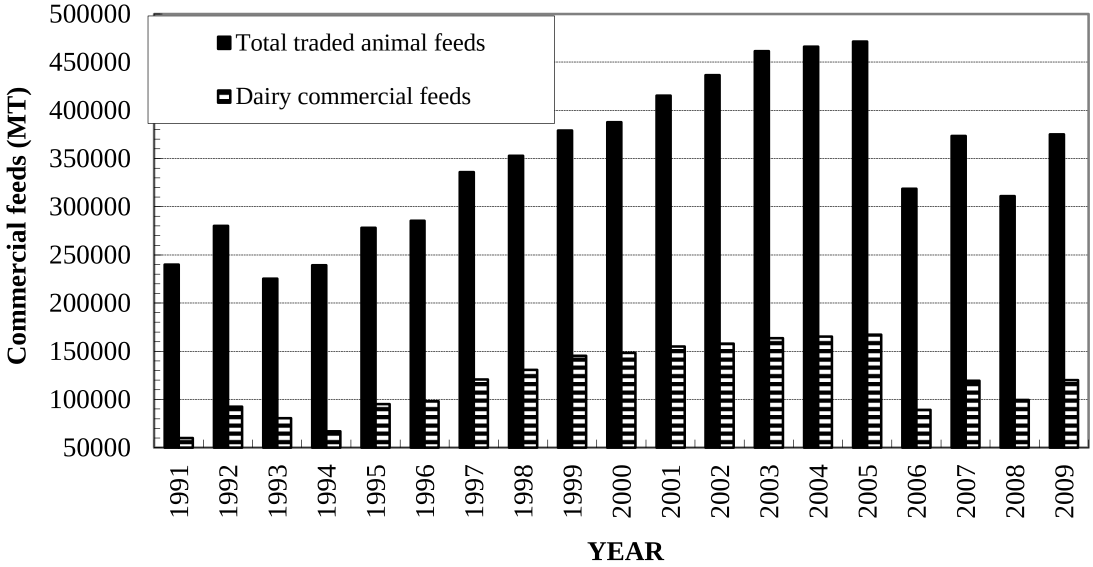

Figure 1: Livestock feeds production trends in MT in Kenya 1991-2009
Source: (MoLD, 2010) Department of Livestock Production, Annual Report

The general increase in traded tonnage reflects a growing market demand for commercial dairy concentrates mainly from smallholder producers accounting (80% of dairy producers in Kenya) of which 74% supplement with different concentrates. Though generally supplementing with limited amounts estimated at 2 Kg of commercial dairy meal (CDM) per cow per day (Table 1), the total volume is significant considering the large population of smallholder dairy producers. Small and medium scale farms supplement between 2.5 and 2.7 Kg of dairy meal per cow per day respectively (Ayako, 2005).

Table 1: Average dairy cattle supplementation levels and prices of concentrate

Farm size	CDM (Kg/cow/day)	HMC (Kg/cow/day)	Total (Kg)	Price CDM (Kshs / 50kg bag)	Price HMC (Kshs /50 kg bag)
Small	2.7	0	2.7	877.50	-
Medium	2.5	0.43	2.93	837.50	-
Large	0	3.0	3.0	-	697.50

HMC= Home Made Concentrate, CDM = Commercial Dairy Meal; Source: Adapted from (Ayako, 2005)

2.2 Dairy concentrate utilisation

In Kenya under smallholder production circumstances, milk yield is estimated at 5 to 7 kg per day per cow from natural grazing (MoLD, 1995) which improves with supplementation to about 7 to 12 kg of milk per cow per day. Dairy meal retails at an average price of Kshs. 20 – 30 per kg whereas the cost of producing 1 kg of milk is estimated at Kshs. 9 –15 (Muriuki, 2006; MoLFD, 2008a), since milk market prices in Kenya are seasonal (Muriuki et al., 2003). During the rainy season when good quality pastures are plenty and milk yields are high, prices are low; but high during the dry season when good quality pastures are scarce. Dairy producers intending to benefit from such high dry season milk prices need to supplement their milking herds with good quality dairy concentrates.

2.3 Pollutant nutrients arising from the use of dairy concentrates

The MDG number 7 and the Kenya's Vision 2030 places special emphasis on sustainable environmental management (Kenya Vision 2030, 2008). Table 2 details the common nutrients excreted from livestock enterprises and their appropriate existing corrective measures. Environmental problems associated with animal manure (CAST, 2002; Dave, 2004) relate mainly to the emission of Nitrogen (N) and Carbon (C) into the air and the leaching of Calcium (Ca) and Phosphorous (P) to ground and surface water. Manure management demand that all intensive dairy production systems with overall nutrient surpluses be improved by adjusting animal diets. Proper modelling of the Kenyan lactating dairy production groups in accordance with existing animal models such as NRC is necessary, thus adopting a broad-based multiple objectives formulation approach.

Table 2: Common elements produced from livestock enterprises

Nutrient	Environmental effects	Corrective measures
Carbon	Air pollution	Planting of trees
Calcium	Formation of scam/ Reduces water quality	Soil vegetation
Nitrogen	Air pollution with ammonia and thickness to Ozone layer	Effective micro-organisms (EM) technology
Phosphorous	Oxygen tension killing aquatic life and algae growth, Eutrophication	None: Environmental protection concern

Source: (CAST, 2002) Annual Conference Report

According to Lekasi et al., (2001a), the live body weight (LBW) of ruminants can be used to estimate the maximum quantity of manure produced, expressed as 0.8 % of BW as a theoretical maximum amount of faecal dry matter (DM) daily. However, the calculation assumes no loses in DM. Ruminant holdings on farms of varying size and estimated annual production of faeces/ha, is based on that theoretical maximum calculation for cattle under permanent confinements throughout the year; at varying plane of nutrition and feeding regimes. Owing to land size constraints, small, medium and large farms practice intensive, semi-intensive and extensive production systems respectively. The small holders tend to collect more manure than both the medium and large farms combined owing to their numbers as shown in Table 3. Much of the manure is consequently utilized as organic fertilizer in the production of food as well as pasture and fodder crops in the smallholder farms.

Table 3: Estimated production of faeces/ha/year from ruminant holdings of varying sizes

Farm size	Mean (and range of) ruminant herds			Mean (and range of) estimated production of faeces (t DM/ha/yr)
	Exotic cattle	Zebu cattle	Small ruminants	
Small	3.1 (1-9)	1.5 (0-9)	1.5 (0-9)	8.2 (3.1-18.9)
Medium	3.5 (1-11)	2.3 (0-8)	2.3 (0-8)	3.6 (0.5-10.2)
Large	5.4 (0-20)	1.2 (0-5)	4.6 (0-21)	2.2 (0.1-5.1)

Source: Adapted from Lekasi et al., (2001a)

The NRC (2001) approach to estimate dietary requirements of cattle for various physiological functions; (maintenance, growth, pregnancy, and lactation), have been explained by Varela-Alverez and Church (1998). Table 4 details the recommended phosphorous feeding levels for lactating dairy cows. Based on the NRC (2001) model the absorption coefficients for P vary from ration to another depending on the specific set of ingredients included in the feed. Matching feed P content (%) to the amount of milk produced by different lactating groups within a herd is absolutely critical (Morse et al., 1992). To do this effectively good knowledge about the rate of feed intake of different lactating groups is paramount; although minimum P-level in feeds has not yet been addressed as a critical formulation goal by available dairy feed formulation programs (Morse et al., 1992; Dave, 2004). The NRC (2001) feeding recommendation for P concentrations for high producing cows ranges between 0.32% and 0.38%, since cow milk contains on average 0.09 % P. However, experimental feeding trials have shown optimal milk yields with lower P diets (Tozer and Stokes, 2001).

Table 4: Recommended phosphorous feeding levels for lactating dairy cows

Cow Body Weight (kgs)	Dry Matter Intake kg/day	Butterfat (%)	Milk Yield in (Kgs/day)	Feed P (%, on DM-basis)
400	8-15	5.0	7-13	0.32
500	10-17	4.5	13-27	0.35
600	10-19	4.0	20-40	0.36
700	10-20	3.5	27-53	0.38
800	10-20	3.5	33-67	0.38

Source: Adapted from Tozer and Stokes, (2001) In many smallholder production systems in developing countries, manure is considered as important as milk, meat or drought power. A study by Romney et al., (1994) in Zimbabwe recorded that producers reduced grazing time by keeping cattle longer in pens in order to collect more manure even though this meant reduced feed intake thereby adversely affecting production. Livestock manure has been identified as an important farm input in small-scale mixed crop-livestock systems (Lekasi et al., 2001a; Ayako, 2005). Manure provides essential soil nutrients, especially Nitrogen, Phosphates, and Potassium. Table 5 presents the Mean, standard deviation (SD) and range of P content in manures from small, medium and large dairy farms in the Kenya highlands. According to Omamo et al., (2002), use of livestock manure in the Kenya highlands has been on the increase among smallholder producers due to its substitutability for inorganic fertilizers as the cost of the later rises due to market distortions, resulting from physical constraints such as road infrastructure. Therefore, the continued application of farm yard manure potentially injects excess P into smallholder farms; presenting the environmental risk of gradual pollution of soils as well as ground and surface waters.

Table 5: Mean, standard deviation and range of Phosphorous from Kenya highlands manure

Manure type	N	Mean (%)	Standard deviation	Range
Cattle	55	0.6	0.34	0.19-1.61
Cattle + compost	10	0.44	0.21	0.21-0.90
Cattle: dung + urine	3	0.65	0.36	0.30-1.01
Cattle: fresh dung	2	0.54	0.28	0.35-0.74
Cattle: slurry	2	0.36	0.04	0.33-0.39

Source: Modified from Lekasi et al., (2001a)

Ideally, dairy farms should be environmentally sustainable businesses. Managing both P input and output to achieve zero whole-farm P-balance should be the primary goal of dairy operations attempting to realise environmental sustainability and be in compliance under the new Concentrated Animal Feeding Operations rule and guidelines (CAST, 2002; Dave, 2004). When inputs are greater than outputs, P builds-up in soils over time and the potential for P runoff increases (NRC, 2001). Phosphorous runoff causes oxygen debt killing aquatic life and excessive algae growth which reduce water quality of streams and lakes; such a series of events is not sustainable environmentally (Morse et al., 1992; CAST, 2002).

Legislation in Kenya aims to reduce soil P build-up and losses from livestock systems by controlling manure management (Lekasi et al., 2001a; Lekasi et al., 2001b).

The physical and chemical properties of animal manure are affected by the physiology of the animal, the feed ration as well as the environment (Ayako, 2005). Size of the animal, as measured by its LBW, is perhaps the most important physiological factor; whereas sex, breed, and activity of the animal affect manure properties to the extent that they partially determine the feed conversion efficiency under a given environment. The digestibility of the feed as well as temperature affects the physical composition of manure. Feed quality influences not only the amount of feed the animal consumes daily, but also the chemical composition of manure. Part of the P content in the feed is absorbed, but most is excreted in the faeces (Lekasi et al., 2001a; Lekasi et al., 2001b; Ayako, 2005). Feed spilled on pens floors, or left as feed refuse is included undigested in the manure collected from the animal pens. Consequently, manure from animals in confinements contains almost all the ingredients of feed; some in their original form and others in chemically simpler forms. Inorganic phosphates are mainly utilised in dairy supplements since common organic sources (bone, meat and blood meals) have been banned due to the risk of Mad Cow Disease. Approximately 80-95 % of P consumed by livestock is excreted (Morse et al., 1992; NRC, 2001; Dave, 2004). Phosphorous content of stored manure is estimated at 5g/kg DM and since faecal P is less labile, less of it is lost during manure storage, hence the increased potential for environmental pollution (Lekasi et al., 2001a; Lekasi et al., 2001b; Ayako, 2005). Consequently, diet modification to reduce the potential for P-pollution becomes necessary. Research work is therefore needed to reduce nutrient pollution into the environment through multiple objective feed formulation approaches by the feed manufacturing industry.

2.4 Considerations in dairy feed formulations

The objectives of dairy feed formulation are to design diets that meet cow nutrient requirements and provide maximum economic returns to the dairy producers. Ideally, dairy entrepreneurs wish to feed their cows adequately at a reasonable cost (Mbugua, 1999; Muriuki, 2006). However, there are two distinct types of diets: those that have the lowest cost and those diets that provide maximum economic returns (Andkinson et al, 1993; Bouwman, 1999), depending on their nutrient supply.

Until 1951, much of dairy feed formulation was based mainly on trial and error methods. Waugh (1951) cited by Varela-Alverez and Church (1998) defined the feeding problem in a mathematical form. Figure 2 illustrates the developmental progress of feed formulation programs over the years. Existing dairy formulation computer programs (up to 1997) such as FeedMix®, BestCombination®, and FeedSoft® programs are based on least cost formulation. Later versions (from 1997 up to date) like FeedWin®, WinFeed®, MakeFeed® and PCDairy® programs have now been equipped with an auto-balancing optimisation to find the least cost combination of ingredients within set maximum profit constraints (Tozer and Stokes, 2001). However, they demand that users avail specific ingredients for the auto-balancer to yield results as defined. Presenting a narrow decision-making base to dairy feed manufacturers who in reality may have other formulation objectives to satisfy.

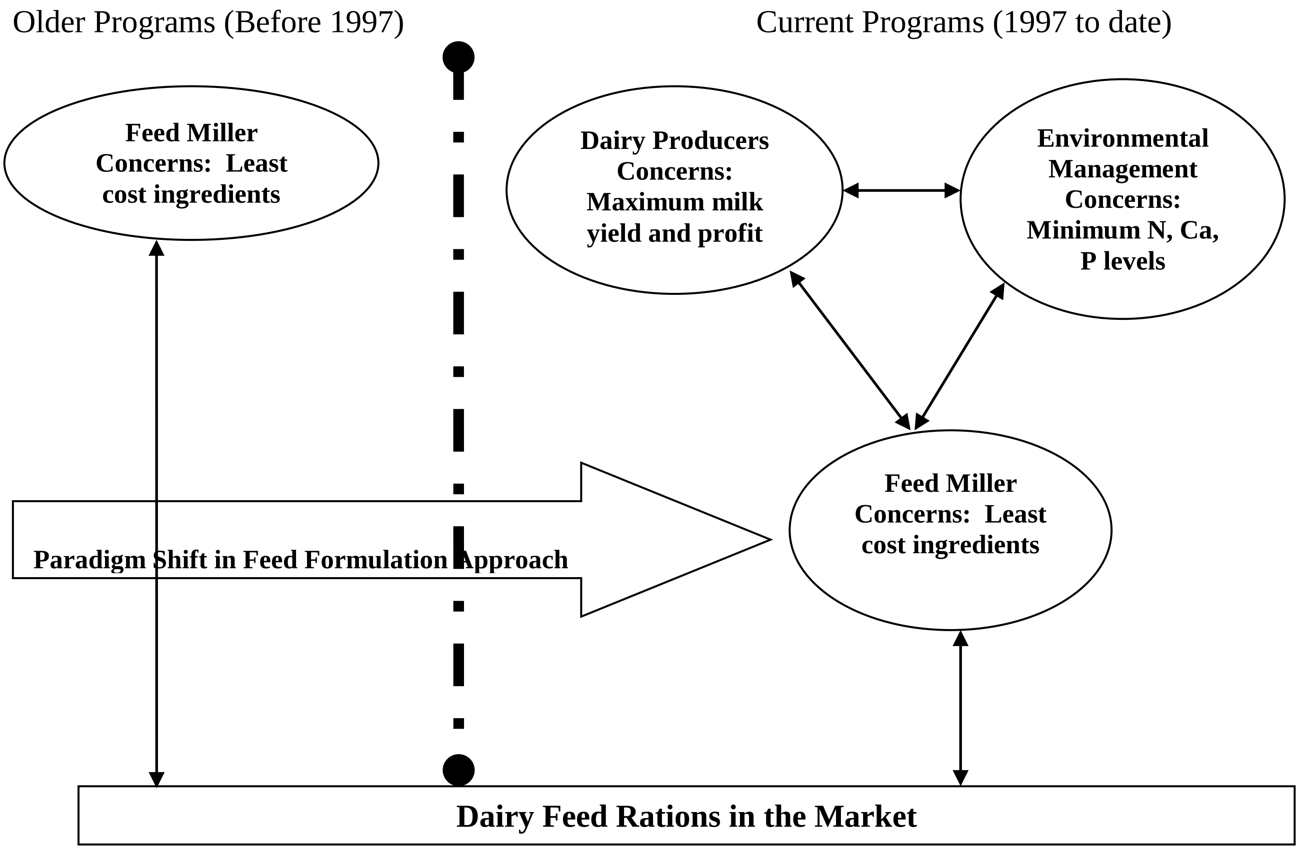

Figure 2: Development of dairy feed formulation programs for the feed industry

In Kenya, dairy nutrient requirements are specified by KEBS, which are modifications, based on the NRC publications in the series of nutrient requirements for domestic animals. Each of these publications contains tables of nutrient requirements for cows of various performance functions (maintenance, growth, reproduction and production). The requirements are expressed as amounts per unit diet (%, g/kg) or as amount per animal per day, especially when feed intake needs to be precisely controlled to allow for greater efficiency in meeting nutrient needs. These values are the minimum requirements for optimal production and do not include a safety margin. Many nutritionists use their judgement to provide a margin of safety by increasing the values by 5% or 10% and sometimes more (KEBS, 2008; Chesworth, 1992; NRC, 2001). However, environmental conditions, stress, animal housing conditions, breed or strains of animal, disease incidence, and projected length of feed storage are factors that might influence selection of an appropriate margin of safety.

Preston and Leng, (1987) are proponents of the viewpoint that application of the NRC philosophy in developing countries is inappropriate and that instead; the objective should be to optimise the use of locally available feed resources and minimise the use of imported ingredients. Under these conditions, NRC requirements generally cannot be economically achieved and thus optimal production is less than maximal. Nutrient requirements are continually "fine-tuned" as new research becomes available and also as animal genetics and management systems change. The almost universal use of computer technology has eliminated the need to formulate diets by hand calculation (Bouwman, 1999; NRC, 2001, Tozer and Stokes, 2001; Waldner, 2003). Using a computer program demands that the entire tables of NRC values be entered into a computer program to serve as the software model layer upon which diets may be formulated so that for each nutrient, the listed requirements is met or exceeded.

Extensive tables of feedstuffs composition are available (NRC, 2001; Muia et al., 2005); whereas requirement values and nutrient level data can be placed in computer files. In the near future, it is anticipated that standard computer lists of ingredient composition will become available commercially. Most feed companies have proprietary files of ingredient composition for feed formulation. However, feedstuffs are inherently variable products; their composition is greatly influenced by harvesting conditions, environmental factors, fertilisation, and irrigation practices (NRC 1989; Chesworth, 1992; NRC, 2001). Thus considerable judgement is needed in assessing whether an apparent deficiency of a particular nutrient is truly important.

Costs of ingredients vary according to a number of factors. The ingredient in largest supply will most likely dictate prices for the other ingredients. For example the plant protein source in Kenya is dominated by cotton seedcake meal. The cost of cotton seedcake meal is largely dependent on crop yields in Uganda and Tanzania, (MoLD, 2009), which in turn are influenced by planted acreage, weather conditions, and other world surpluses. The cost of other protein concentrate sources such as sunflower, copra and soybean cakes are pegged on cotton meal prices. In least-cost feed formulation, the prices of available ingredients are entered into a computer program. These prices may change on a daily or weekly basis. The computer solves an array of simultaneous equations to provide the solution for the least-expensive combination of ingredients to satisfy the requirements of each nutrient. For multiple feed formulations, an iterative selection on the basis of quality for potential high milk production, minimum excess nutrient excretion and least-cost ingredient combinations are integrated in a programming approach.

2.5 Approaches in dairy feed formulation

Formulating feed to fulfil the nutrient requirements of a cow at lowest possible cost (least-cost feed), by hand calculation is difficult because it requires tremendous amount of time when large amounts of ingredients and nutrients needs have to be considered. Computer programs have been developed that allow for the calculation of optimum diets in a matter of seconds. Such programs are now available on computer hardware and software (Waldner, 2003) at reasonable cost to dairy producers. With the use of computerised LP models, the prices of available ingredients as well as their nutrient contents can be considered when formulating dairy feeds. A least-cost computer program can test all combinations of available ingredients and then select the mixture that fulfils the nutrient requirements at the lowest cost possible. A dairy producer may therefore save on feed cost with no reduction in cow performance by formulating feeds using least-cost approach. However, the lowest cost diet, even though it may be nutritionally adequate, may not be the most economical (Chesworth, 1992; Bouwman, 1999; Tozer and Stokes, 2001); since it is the net returns from the use of the diet which are indicators of economic efficiency in the interest of dairy producers.

Sustainable dairy farms are developed for the future where changes are made to improve their productivity, profitability and environmental impact. Changes that require little investment include modified feed formulation and more efficient supplementary feeding to reduce the nutrient levels in manure. Operational research and management sciences deal with the application of information technology for informed decision-making (Tozer and Stokes, 2001; Thorne and Dijkman, 2005). Much of such work is done using analytical and numerical techniques to develop and manipulate mathematical and computer models of organisational systems composed of people, processes and procedures (Heard et al., 2004).

Mathematical models of animal growth, development and physiology are now integral to Animal Science; including dairy feed formulation which emphasises on least cost models to diet balancing (Nagorcka et al., 2004; Conception, 2006). However, as alluded to earlier, this formulation function approach has many limitations (Tozer and Stokes, 2001; Waldner, 2003) and this is probably the reason that it has failed to address emerging business, production, and policy needs within dairy farms.

Information needs and related technologies are now a must for sustainable dairy farming (Asseldonk et al., 1999). Designing efficient dairy feed formulation programs requires analysing three main dimensions. Firstly, the feed manufacturing chain (Dwight and Keith, 1996) with all the dependencies among domain stakeholders; secondly, the technical dimension concerning feedstuffs, nutrient composition, dairy cattle nutrient requirements, and the techniques of dairy feed formulation (Thorne and Dijkman, 2005); and thirdly the feed policy environment within a country. These considerations, according to Kange'the (2002) motivate the choice of a process model and design approach for software development. The Iterative Modelling, as advanced by the Software Engineering Best Practices of 1998, is the most recent and widely used technique. It is characterised by user involvement throughout the project life cycle and continuous system improvement based on user feedback. Additionally, the Object Oriented Design (OOD) approach which is programming oriented, with the potential to shorten the software development lifecycle (Booch et al., 1996; Shen et al., 2003), offers the most appropriate design technique.

The Object Oriented Design (OOD) technique has relevance in feed formulation. Booch, et al., (1996) defines object-oriented design (OOD) as a method of design encompassing the process of object-oriented decomposition and a notation for depicting logical and physical as well as static and dynamic models of the system under design. Specifically, OOD uses classes and objects to structure systems, as opposed to algorithmic abstractions used by structured design. It also uses a notation that expresses classes and objects (the logical decomposition) as well as modules and process (the physical decomposition).

According to Booch, et al., (1996), there are four major elements of the Object Model: Abstraction, Encapsulation, Modularity, and Hierarchy. Abstraction is the process of identifying the essential characteristics of an object that distinguish it from all other kinds of objects. Basically it is identifying program classes and objects. Encapsulation is another term for information hiding, while abstraction focuses on how the object is viewed from the outside, encapsulation focuses on what can only be seen from inside the object perspective.

Modularity refers to program partitioning. It creates well-defined, documented boundaries within a program. These boundaries provide logical separation between the objects of an application and reusable parts. Sometimes they are used to partition out the work to individual programmers; whereas hierarchy is the ranking or ordering of abstractions, to structure complex system into class structure as well as object structure (Booch, et al., 1996; Doug and Patti, 1992; Predita, 2000).

A model should have all four of these elements to be object-oriented. In addition, there are three minor elements of the Object Model (OM) namely; Typing, Concurrency, and Persistence. Each of these elements is useful to the model, but not essential. The elements of the OM help to make use of the full power of the object-oriented language (e.g. VB.Net Scripting) used for implementation. Nevertheless, the hardest part of object-oriented programming is coming up with the best set of objects to describe the problem domain (Booch, et al., 1992; Doug and Patti, 1992), especially in a complex and ever changing environment like the feed manufacturing dimension (Dwight and Keith, 1996). Under such circumstances, it becomes necessary to analyze the problem domain and design a system that meets user requirements, before implementing it, otherwise it is possible to develop code that is not reusable, or continually needs to be "patched" or rewritten. Consequently, it lends itself well to an object-oriented implementation (Doug and Patti, 1992) and in the end leads to more manageable code.

Until recently, structured programming techniques were the most widely used for all phases of software development, from analysis and design to implementation. However, as systems increase in complexity, software modelling using structured programming techniques has become limiting (Doug and Patti, 1992) owing to growing needs for software manageability, code reuse, and continual change. Good software development must begin with a good design and object-oriented programming (OOP) offers the potential to solve many of the problems of programming complex systems; such as the MoF-Dairy Edition (2010), the developed program in the current study. A good design needs a good analysis of the problem domain for ease of implementation thus OOP needs both an analysis and design technique suited to the methodology.

A multi-objective dairy feed formulation approach may be necessary to allow for incorporation of milk production levels, environmental nutrient pollution concerns as well as feed cost implications to optimise the diverse interests of the various actors in the feed industry. The approach aims at providing broad decision-making base to formulators of dairy feeds by employing the use of linear as well as non-linear programming to derive the best combination of ingredients (Dave, 2004), to achieve lowest possible cost that maximise milk production and profits while maintaining minimum P-excretion into the environment. To model milk profit maximisation and P-excretion, Tozer and Stokes (2001) as shown in Figure 3, suggested the necessity to augment the simple LP feed formulation model beyond intake levels to include milk yields and P-excretion objective functions (Varela-Alverez and Church, 1998). However, the programming approach depends on nutrient intake to maintain simplicity.

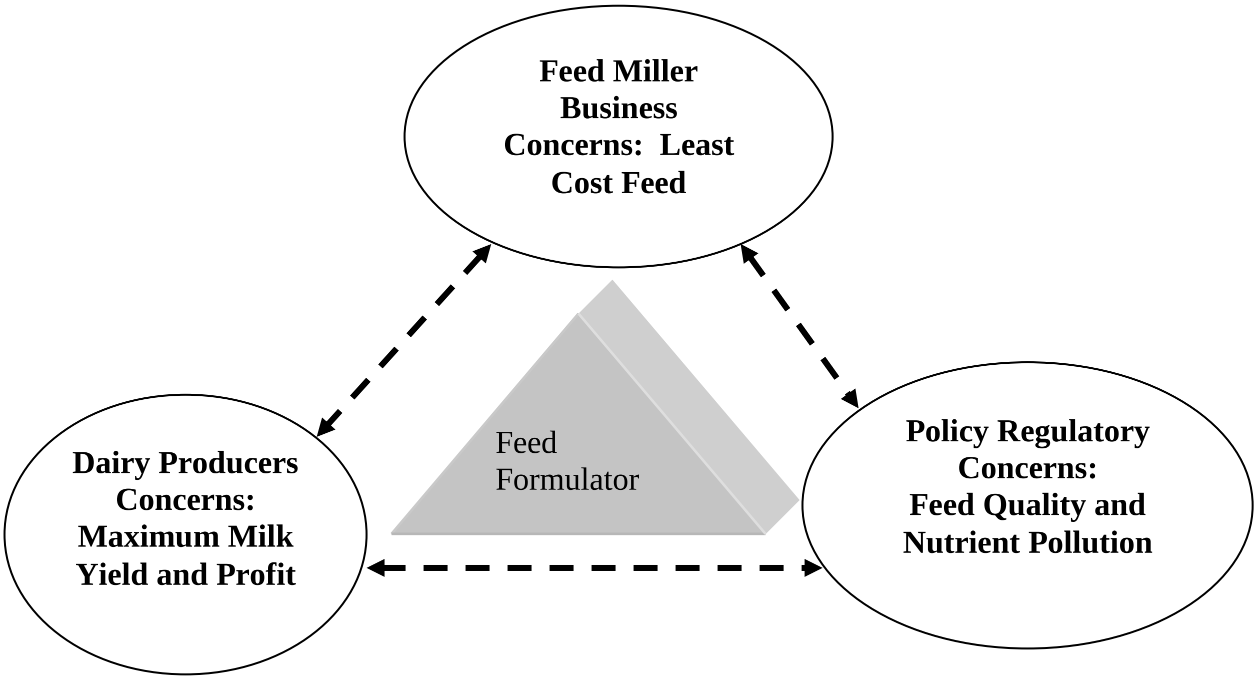

Figure 3: Structure of multiple objectives formulation approach

CHAPTER THREE
RELATIONSHIP OF FEED FORMULATION GOALS AMONG FEED MILLERS, DAIRY PRODUCERS, AND POLICY REGULATORS IN KENYA

Abstract

The least cost goal in dairy feed formulation satisfies the millers' objectives of minimising feed costs and maximising manufacturing profits. However, there exists apparent conflict of the objectives among dairy producers intending to maximise income above the market price of feed and the policy regulatory objectives of feed quality standards as well as limit excretion of excessive pollutant nutrients from dairy enterprises into the environment. To determine the relationship between industry players' interests on feed processing and utilisation and the critical feed formulation goals, a survey was conducted among feed millers, dairy producers, and policy regulatory authorities responsible for feed quality standards and environmental health. The relationship was examined using the Kruskal-Wallis test for independent samples. Specifically, the aim was to evaluate differences among feed industry actor opinion scores (feed millers, dairy producers, KEBS and NEMA) based on the four critical feed formulation goals (feed cost, milk production, feed quality and nutrient pollution). A post-hoc analysis (Mann-Whitney U test for independent samples) was conducted to evaluate pair-wise differences among the four groups, controlling for Type I error across tests by using the Bonferroni approach. Results revealed statistically significant difference in opinion on feed cost, H (3), (N = 78) = 52.24, p = 0.00; milk production, H (3), (N = 78) = 25.97, p = 0.00; feed quality, H (3), (N = 78) = 42.46, p = 0 .00 and nutrient pollution H (3), (N = 78) = 16.49, p = 0.001, among the four feed industry actor groups; representing an underlying conflict in dairy feed manufacturing decision-making process. Solutions to these limitations will include innovations towards the development of broad-based multiple feed formulation approaches that attempt to collectively optimise stakeholder needs step-wise. Determination of such relationships is important to livestock development partners in their effort to formulate policies for practical feed manufacturing to support sustainable dairy entrepreneurship.

Keywords: feed industry, least-cost feeds, ingredient cost, milk profits, nutrient excretion

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3.1 Introduction

Animal feeding influences livestock productivity, profitability of farm business growth and environmental management (Muriuki et al., 2003; Technical team, 2003; Muriuki, 2006; MoLDF, 2007; EC-DG, 2008). Domain stakeholders in the feed industry include feed millers, dairy producers, and regulatory agencies for feed quality standards and environmental pollution; the Kenya Bureau of Standards (KEBS) and the National Environment Management Authority (NEMA) respectively-whose critical feed formulation objectives include; (least cost of ingredients, maximum milk profit margins, feed quality and minimum nutrient excretion) are diverse and conflicting. While KEBS is the national government agency regulating dairy feed quality specifications, NEMA is responsible for environmental health issues by regulating the amount of pollutant nutrients from livestock enterprises practicing concentrate feeding.

Presently, feed millers implement these quality regulatory guidelines by employing the singular objective of least-cost approach to dairy feed formulation. However, the growing demands for quality feeds by dairy producers intending to exploit the full production potentials of their cows, in addition to emerging environmental pollution concerns from dairy enterprises through excessive pollutant nutrients in manure (such as P) is exerting new challenges on animal feed millers. Critical feed formulation objectives of feed industry stakeholder groups need to be significantly strong and positively correlated; if they are to be optimised during feed formulation in practice (Knowlton et al., 2004). Such a correlation can best be entrenched in the dairy feed manufacturing process and manifested in a formulation approach that meets overall industry expectations. Unfortunately, feed industry actors have continued to firmly hold on to their entrepreneurial needs as well as organizational mandates without due regard to key formulation goals and expectations of the other industry players.

There is limited information regarding the association between feed formulation objectives of millers, dairy producers, and policy regulators, mainly because such a research undertaking has not been performed in Kenya as yet. In an attempt to effectively address emerging business, production, as well as environmental challenges in the feed industry, determination of the relationship between critical dairy feed formulation goals becomes important. Such an association has not been quantified in earlier surveys on production and use of concentrates, policy environment and lessons on dairy development in the smallholder dairy sub-sector (Mbugua, 1999; Muriuki et al., 2003; Muriuki, 2006). To address the existing knowledge gap, the current study was conducted to determine the relationships of feed formulation goals among domain actors in the feed manufacturing industry

3.2 Materials and methods

3.2.1 Study area

The survey was conducted in Nakuru district which is a prominent dairy producing area with the highest number of dairy cattle in Kenya estimated at over 251, 000 heads (MoLFD, 2006a; MoLFD, 2007) and is home to 23% of total feed mills in Kenya. Only one feed miller is large scale and fairly automated. The rest range from small to medium scale capacity and are either manual and/or semi-automated. About 80% of the dairy producers in Nakuru are smallholders (MoLFD, 2006b), representing a potentially sizeable consumer population for commercial dairy feeds, since they do not practice on-farm concentrate feed milling. Commonly used ingredients in dairy feed manufacturing include cereals and cereal-by products, oil-seed cake meals, mineral concentrates, and dairy premix concentrates (mineral + vitamins).

3.2.2 Survey methodology

The study was conducted in Nakuru district between September, 2009 and April, 2010. The purposive sampling technique was used to select 78 respondents comprising 19 feed millers, 37 smallholder dairy producers and officials from the regulatory authorities of which 10 were from feed quality standards agency (KEBS) and 12 from the national environment management authority (NEMA) regulating pollutant nutrients. Registered feed millers were visited and each was asked to identify two regular dairy producers and/or stockists customers from their monthly feed purchase volumes and the regulatory agency officials whom they interacted with on matters of feed quality and environmental pollution. The approach was used to recruit the most progressive dairy producers in the area. Recruited respondents practiced intensive smallholder dairy farming and were drawn from the rural and peri-urban areas of Nakuru district. They were members of existing Common Interest Groups (CIGs) under the Smallholder Dairy Commercialisation Programme (SDCP) of IFAD-Kenya Project in the Ministry of Livestock Development.

3.2.3 Data collection

Data collection was conducted using a pre-tested structured questionnaire which was administered to the four stakeholder groups. The study instrument had four parts each on feed milling, dairy production, KEBS and NEMA concerned with feed quality standards and nutrient pollution respectively. Data collected on least cost ingredient objective included familiarity with dairy feed formulation, cost and quality consideration during feed formulation, and ingredient availability. Data collected on maximum milk production and profits objective focused on prioritisation of milk production and profits in dairy feed manufacturing, complains about high feed prices and low milk production, and comparison of dairy feed prices, quality levels and guarantee for profitability, whilst data was collected on minimum nutrient excretion in manure objective with regard to adherence to feed quality specifications and observance of policy regulatory requirements for manure waste disposal for a healthy environment. Each stakeholder scored the relative importance (opinion score) of the four dependent variables on a 5-point Likert scale thus: strongly disagree (1), fairly disagree (2), undecided (3), agree (4), and strongly agree (5); and data computed to determine the relationship in the opinions on feed processing and use among feed industry actor groups.

3.2.4 Statistical analysis

The statistical significance of difference in opinion scores among the feed industry actors (feed millers, dairy producers, KEBS and NEMA) across feed formulation goals (feed cost, milk production, feed quality and P-manure pollution) was determined by the Kruskal-Wallis-H test using the K independent sample procedure. The non-parametric alternative to ANOVA for testing for difference between several independent groups which is based on ranked data (Teodora, 2008). The test statistic *H* was calculated thus;

$$H = \frac{12}{N(N+1)} \sum \frac{R_i^2}{n_i} - 3(N+1)$$

Where N = total number of replications, n_i = sample size and R_i = sum of ranks.

A post-hoc comparison (Mann-Whitney U test for independent samples) was used to calculate the specific group pair-wise difference since the factor had more than two levels and the overall test was significant. The magnitude of the observed opinion differences (r) was calculated thus;

$$R = \frac{Z}{\sqrt{N}}$$

where N is the total number of the samples and Z represents the distance between the raw score and the population mean.

3.3 Results

3.3.1 Differences of industry actors opinion on feed processing and use

A Kruskal-Wallis test was conducted to evaluate the difference between industry actor (feed millers, dairy producers, KEBS and NEMA) opinions on feed processing and use; across the four critical feed formulation goals (feed cost, milk production, feed quality and nutrient pollution). The test, which was corrected for tied ranks, showed statistically significant difference in opinion on feed cost, H (3), (N = 78) = 52.24, p = 0.00; milk production, H (3), (N = 78) = 25.97, p = 0.00; feed quality, H (3), (N = 78) = 42.46, p = 0 .00, and nutrient pollution H (3), (N = 78) = 16.49, p = 0.001; among the four feed industry actor groups as shown in Table 6.

Table 6: Differences of industry actors opinion on feed processing and use

Feed formulation goals	Actors	Mean rank	Kruskal-Wallis H value	P-value
Feed cost	Feed Millers	67.05	52.24	0.000
	Dairy Producers	22.18		
	KEBS	50.45		
	NEMA	40.17		
Milk production	Feed Millers	60.47	25.97	0.000
	Dairy Producers	29.04		
	KEBS	45.70		
	NEMA	33.38		
Feed quality	Feed Millers	65.39	42.46	0.000
	Dairy Producers	26.96		
	KEBS	51.00		
	NEMA	27.58		
Nutrient pollution	Feed Millers	49.05	16.49	0.001
	Dairy Producers	29.68		
	KEBS	38.70		
	NEMA	55.33		

Follow-up tests were conducted to evaluate specific pair-wise differences among the four groups, controlling for Type I error across tests by using the Bonferroni approach. The post hoc test analysis identified the exact test cases for significant statistical differences by using the Mann-Whitney U method as shown in Table 7. The tests revealed a significant difference between the industry stakeholder opinions on feed formulation goals for all the cases.

Table 7: Multiple comparison of difference in opinion on formulation goal by actor pairs

Feed formulation goals	Feed industry actors	Magnitude of observed difference r	P-value
Feed cost	Feed Millers and Dairy Farmers	0.81 [a]	0.000
	Feed Millers and KEBS	0.58 [a]	0.002
	Feed Millers and NEMA	0.77 [a]	0.000
	Dairy Farmers and KEBS	0.59 [a]	0.000
	Dairy Farmers and NEMA	0.46 [a]	0.001
	KEBS and NEMA	0.32 [NS]	0.136
Milk production	Feed Millers and Dairy Farmers	0.63 [a]	0.000
	Feed Millers and KEBS	0.32 [NS]	0.084
	Feed Millers and NEMA	0.63 [a]	0.000
	Dairy Farmers and KEBS	0.30 [a]	0.037
	Dairy Farmers and NEMA	0.11 [NS]	0.462
	KEBS and NEMA	0.27 [NS]	0.208
Feed quality	Feed Millers and Dairy Farmers	0.78 [a]	0.000
	Feed Millers and KEBS	0.43 [a]	0.021
	Feed Millers and NEMA	0.78 [a]	0.000
	Dairy Farmers and KEBS	0.48 [a]	0.001
	Dairy Farmers and NEMA	0.01 [NS]	0.953
	KEBS and NEMA	0.56 [a]	0.009
Nutrient pollution	Feed Millers and Dairy Farmers	0.41 [a]	0.002
	Feed Millers and KEBS	0.19 [NS]	0.310
	Feed Millers and NEMA	0.13 [NS]	0.472
	Dairy Farmers and KEBS	0.16 [NS]	0.283
	Dairy Farmers and NEMA	0.49 [a]	0.001
	KEBS and NEMA	0.38 [NS]	0.076

[a] 2 tailed statistical significance at 0.05 level; NS = Not Significant

3.4 Discussion

3.4.1 Effects of feed formulation goals on dairy feed processing and utilization

Business considerations

Feed millers are increasingly interested in low ingredient costs with the desire of manufacturing quality feeds that guarantee high income over feed costs (IOFC) (Mbugua, 1999; Muriuki, 2006); for the benefit of dairy producers as well as adhere to quality regulatory specifications (KEBS, 2008). But they are often limited by the formulation approaches (Knowlton et al., 2004), currently available in the market since they are designed to optimise only one goal, the least cost. Feed millers have a responsibility to remain in economically gainful business and as such feed cost and feed quality presented the strongest conflict across industry actors (Table 6); when compared with potential for milk production from dairy cows supplemented with commercial concentrates that have minimum excretion of P-manure. Thus supporting the common field observations that commercial dairy concentrates in Kenya, are characteristically expensive and of variable nutritional quality (MoLFD, 2006b). Feed millers were familiar with dairy feed formulation and manufacturing process including; inherent constraints of ingredient availability and cost, which occasionally present challenges in their attempts to balance feed cost with quality regulatory specifications (KEBS, 2008; Muriuki, 2006).

Feed is the major cost to milk production, accounting for about 50 to 70% of total cost (Jones et al., 1980; MoLD, 1995; Muriuki, 2006; MoLFD, 2007; MoLD, 2008b). Reduced feed costs or quality feeds guaranteeing increased milk production, while maintaining minimum nutrient pollution (Dave, 2004; Muriuki, 2006), present an opportunity to increase farm net returns. Unfortunately, it remains a rare scenario under tropical dairy farming conditions where ingredient costs and availability throughout the year are erratic.

Production considerations

Dairy producers continue to view dairy farming as a business. Their expectations are high and immediate following the purchase and supplementation of dairy concentrates to lactating cows. Feed cost and milk yields are the two most important areas of production management for increasing IOFC. Probably industry actors had the feeling that feed quality was never balanced to fully exploit the potential production of dairy cows; since dairy producers are mainly interested in high milk production to optimise on profits. Test difference for the milk production goal was significant for all the industry actors representing a modest conflict compared with the feed cost and feed quality goals. While feed millers are interested in low ingredient costs for the benefit of their manufacturing business economics, dairy producers are mainly concerned with affordable quality feeds that guarantee high milk production sustainably (Mbugua, 1999; Muriuki, 2006). Unfortunately, low ingredient costs often correspond to low feed quality which is likely to violate KEBS regulatory specifications. Coupled with unstable milk pricing schemes, they are likely to impact negatively on concentrate dairy feed manufacturing. Consequently, milk yields and feed costs remain the two most important areas of management for increasing IOFC for the individual dairy producer.

In most cases, milk price is dictated by market supply and demand (Muriuki et al., 2003; Muriuki, 2006; MoLFD, 2006b), and to some extent by government pricing thus exposing dairy producers to marginal profits which fluctuate seasonally. Although on-farm trials with pasture-oriented farms in Louisiana and Ireland (Andkinson et al., 1993; McEvoy et al., 2008) and concentrate feeding in Kenya (Mbugua, 1999; Muriuki, 2006), have reported that increased dietary concentrates is associated with increased milk yield, they all realised lower IOFC in general.

Policy regulatory considerations

The Kenya Bureau of Standards is responsible for the development and enforcement of feed quality standards for commercial and on-farm dairy concentrates. The test evaluation for differences in feed quality was significant. Consequently, the perceptions of the feed quality goal by industry actors were divergent; implying an existing dissatisfaction with quality levels of commercial dairy concentrates. Demonstrating the common tendency of regulatory agencies to enforce guidelines without due considerations of business economic implications of the affected entrepreneurs.

The national environment management authority regulates recommended levels of pollutant nutrients from dairy enterprises practising concentrate feeding. Quality feeds adjusted to standard dairy cow nutrient requirements (NRC, 2001), guarantees minimum excretion of pollutant nutrients into the environment. Nutrient environmental pollution posted the lowest test difference. It can be deduced that industry actors may have paid less attention to the environmental goal unawares since they did not consider manure as a major environmental pollutant (Dave, 2004).

3.4.2 Implications for ration formulation approaches in dairy feed manufacturing

In common with other developing countries, the production of cereal grain crops in Kenya is destined for human consumption. Consequently, only the milling-by-products such as maize bran, wheat bran, rice bran and oil-seed cake meals (MoLFD, 2006a) are available for livestock feeding. Poor ingredient availability planning alone could not contribute to the illustrated differences among actors in dairy feed industry, since it is seasonal (Thorne and Dijkman, 2001). The dairy feed manufacturing process-including the use of the singular objective feed formulation programs based on least cost approach to feed composition are the other probable contributors. Especially, considering that the feed industry stakeholders have multidimensional objectives which need to be addressed collectively by optimising them in feed processing stepwise (Tozer and Stokes, 2001; Knowlton et al., 2004).

Feed formulation and manufacturing, dairy farming and feed regulation represent people, process, product, consumer, and policy actor-linkages within the feed industry stakeholder groups. Available commercial dairy feed in the Kenyan market are compounded based on the singular objective formulation approach; which considers ingredient costs as the only determinant to feed composition. Unfortunately, the formulation approach does not impose minimum nutrient excretion in manure (CAST, 2002; Dave, 2004) as a critical feed formulation goal. Therefore, the continued utilization of commercial dairy feeds could slowly but cumulatively be causing eutrophication of aquatic life through excess P-excretions in manure unnoticed. The fact that nutrient pollution showed a significant difference between the four formulation goals across the industry actors confirmed how least NEMA was involved in dairy feed manufacturing process; and yet its mandate is to regulate water quality and waste disposal into the environment; including manure waste disposal from livestock enterprises.

Feed millers have the interest of dairy producers at heart when manufacturing concentrate feeds as demonstrated by the participation of some large feed mills in training seminars for livestock producers, pointing out the benefits of feeding balanced nutritious diets (TWG, 2006); and would wish to adhere to feed regulatory specifications (KEBS, 2008). However, they are constrained by available feed formulation programs which are based on LP approach (Black and Hlubik, 1980; Waldner, 2003); which is characterized by a generalised inability to optimise the four critical formulation goals. Rehman and Romero, (1984); Lara, (1993); Varela-Alverez and Church; (1998) and Tozer and Stokes, (2001) have equally criticised typical LP approach for rigidly imposing the singular function because of the many limitations experienced when formulating feeds in practice.

3.5 Conclusion

The relationship between the interests on feed processing and use among the feed industry actor groups showed significant differences; demonstrating a diverse and conflicting scenario. Thus, pointing to the conclusion that the current singular objective formulation approach is a limiting factor in dairy feed manufacturing since it does not address the multidimensional stakeholder needs collectively. Additionally, the assumption that available commercial feeds meet dairy producer needs as well as satisfy government feed policy regulatory requirements is misleading. Consequently, sustainable dairy feed manufacturing will depend upon finding solutions to such conflicts. Solutions to these limitations will include innovations towards the development of broad-based multiple objective formulation approaches that attempt to collectively optimise diverse stakeholder needs step-wise.

CHAPTER FOUR

MULTI-OBJECTIVE DAIRY FEED FORMULATION SOFTWARE: PROGRAM DESIGN AND DEVELOPMENT

Abstract

Predictive functions for milk yield (MY), dry matter intake (DMI), and phosphorous (P)-manure derived from the NRC (2001) and research observations were incorporated in the development of the proposed multiple objectives dairy ration formulation program MoF-Dairy Edition (2010); that optimises feed cost, milk yield and profits as well as minimise P-excretion in manure. Important objects in the feed milling industry considered in the program development are feed millers, dairy producers, and government feed policy regulatory guidelines. The multi-objective formulation approach comprises hierarchical design levels which include data, model, tools, and output layers. Program database (DB) objects are manipulated using VB.NET programming language within a Microsoft .NET Framework Environment. Users interact with the program by providing individual details after which a customer system instance is created. Program formulation inputs are entered through a VB form linked to the core simulation model layer (Microsoft SQL Server Database) which automatically calculates and generates nutrient requirements in accordance with the NRC, (2001) for the particular cow or cow production groups under specified production performance parameters. The final solution is obtained by allowing the program to solve for the most feasible combination of available ingredients under the imposed formulation, ingredient as well as nutrient constraints. Program outputs include tailor-made reports on feed formulae; and the physical nutrient compositions and nutrient deviation analysis; business economic analysis; detailing concentrate supplementation rates per cow per milking as well as the corresponding projected daily milk profit margins and the potential unit and gross P-manure environmental pollution.

Key words: Kenya feed industry; feed formulation model, multiple objectives formulation

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4.1 Introduction

Animal feed formulations are increasingly expected to generate greatest economic return per unit feed cost; at minimum excess manure pollutant nutrient excretion for improved environmental management and sustainable livestock productivity (Cerosaletti, et al., 2004; Chapuis-Lardy, 2004; Carmen, et al., 2005). However, findings from the feed industry study survey (Chapter 3) showed that the four critical feed formulation goals are divergent and conflicting across the key industry players. Suggesting the current singular objective formulation approach is probably limiting. Essentially, satisfying the multiple objectives of the feed millers as well as those of the dairy producers and regulatory authorities is an emerging challenge to feed industry actors. Solutions to these limitations will include innovations towards the development of broad-based multiple feed formulation approaches that attempt to collectively optimise the stakeholder needs step-wise.

This chapter describes the design and development of the proposed MoF-Dairy Edition program which is a combination of linear and non-linear functions. The overall goal is to maximise milk yield, and minimise feed cost as well as reduce excess nutrient excretion into the environment; subject to restrictions specified by the user. Specifically, the methodology integrates feed quality, milk production, nutrient pollution and ingredient cost as the critical formulation goals. Feeds are formulated considering the following nutrients: total digestible nutrients (TDN/energy), crude protein (CP), neutral detergent fibre (NDF), calcium Ca) and phosphorus (P). Previous studies (Brown et al., 1977; Brown and Chandler, 1978; Jones et al, 1980; Rehman and Romero, 1984; Varela-Alverez and Church, 1998; Tozer and Stokes, 2001; Thorne and Dijkman, 2005), on the development of dairy feed formulation systems have mainly focused on the singular objective approach to dairy feed processing. However, emerging challenges in modern dairy farming are driving the need for the development of similar programs that are based on multiple objectives approach. Such an approach has not found widespread application, perhaps owing in part to the limitations of computer technologies as well as a lack of a systematic multiple-objectives approach among earlier studies on dairy cow diet formulation (Chandler et al., 1977; Lara, 1993; Varela-Alverez and Church, 1998; Tozer and Stokes, 2001; Waldner, 2003). The approach can be integrated in the feed manufacturing decision-making process and manifested in a formulation methodology that attempts to incorporate overall industry entrepreneurial needs, institutional policy frameworks as well as regulatory mandates collectively. It was the objective of the current study to incorporate milk yield, dry matter intake, feed cost and P-manure excretion predictive functions in the development of a MOF-Dairy program.

4.2 Materials and methods

4.2.1 Program design and description

Important objects in the feed industry considered in the development of the multi-objective formulation program were represented by feed millers, dairy producers, and feed quality and environmental regulators. The industry actors have conflicting objectives which, the program attempted to optimise (Chapter 3). Dairy producers are the customers who purchase rations to supplement their lactating cows with the aim of increasing nutrient intake for improved milk yield and hence maximise returns from milk sales. The regulators are government agencies whose objective is to provide guidelines regarding adherence to feed quality standards as well as limit environmental P-pollution from dairy enterprises practicing concentrate feeding operations. Feed formulation interests of dairy producers and policy regulatory guidelines were incorporated into a dairy feed formulation process, design and development; in conjunction with feed millers business needs as illustrated in Figure 4.

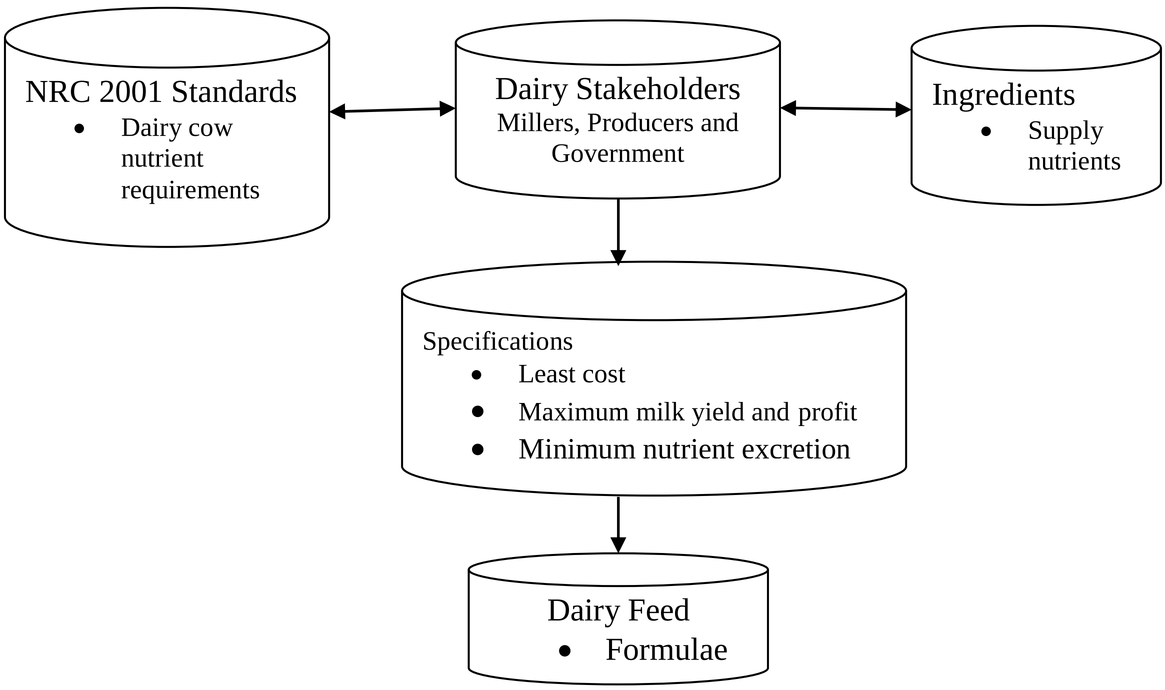

Figure 4: Program data organisation

The program is designed such that available ingredients are used to specify diets for the cow production group. Specification for constraints; e.g. ingredient inclusion levels, daily nutrient intake requirements and excretion limitations, and ingredient cost limits, are set for every instance of a customer. These are implemented in the multi-objective formulation program to generate a dairy feed formula that meets the overall multiple formulator needs for adherence to feed policy regulatory guidelines and acceptable feed quality, while maintaining least cost business goals. Once a formulation is successful, the diet is moved to the formulae section. The ingredients database, dairy cow details and formula data types are owned by a customer and are defined and maintained by the formulation program data layer. However, the formulation program does not define the customised data type representing input data since such data type are used to store information about the animal model NRC (2001).

4.2.2 Program schematic representation

The structure of the program includes: data, model, tools, and output layers as illustrated in Figure 5 where; the data layer represents actors in the feed milling industry and imposed feed formulation constraints as processes. The model layer corresponds to the core simulation model (stored in a Microsoft SQL Database) based on NRC, (2001) dairy cow daily nutrient requirements that is dynamically determined by incorporating the MY, DMI and P-manure predictive functions for lactating dairy cows into the feed formulation process. The tools layer depicts object-oriented 4th generation language which provides the programming environment for generating program-user interactive interfaces that address specific user needs using Microsoft Visual Studio version 6.0 Professional Edition of 2008. The proposed MoF-Dairy Edition program incorporates very powerful scripting which is a dialect of Visual Basic (VB).Net implemented within a Microsoft.Net Framework Environment. The output layer represents the final multi-objective formula based on dairy cow production performance specifications, and prevailing ingredient and nutrient constraints. It generates program reports that serve as decision-making tools under practical dairy feed manufacturing processes.

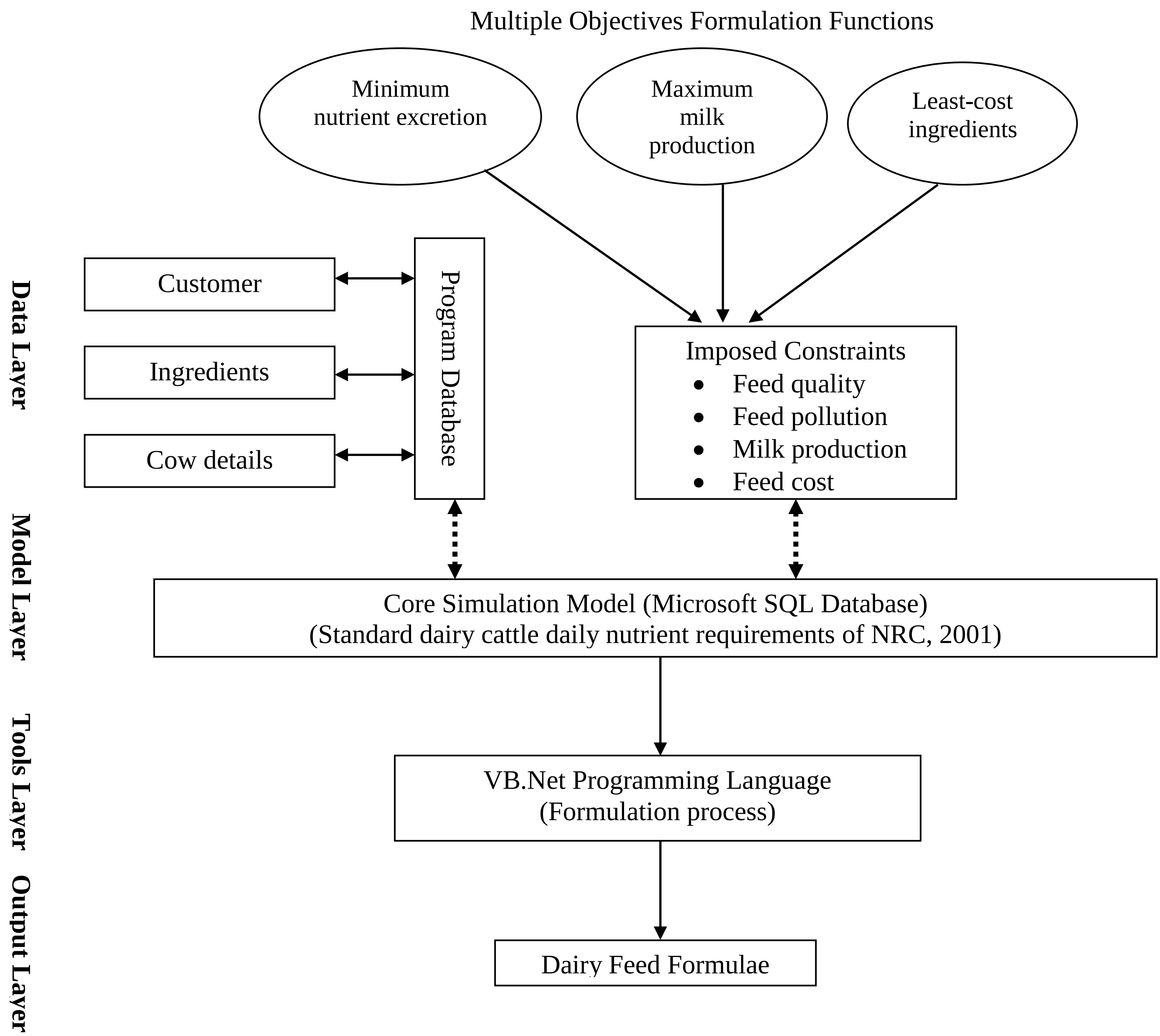

Figure 5: Schematic representation of the multi-objective formulation simulation program

4.2.3 Program development

Incorporating the dry matter intake function

Development of cost effective and quality software programs that address business needs of all stakeholders in the feed industry requires a suitable system development process model to direct the project life cycle (Board, 1998; Kang'ethe, 2002). Hence the iterative modelling technique described by the Software Engineering Best Practices (Board, 1998), was employed in the development of the proposed MoF-Dairy Edition Program. Additionally, incorporation of milk production levels, environmental nutrient pollution concerns as well as feed cost were achieved by integrating ingredient quality ratios into minimum P-excretion and least cost functions (Waugh, 1951; Morse et al., 1992; Varela-Alverez and Church, 1998). The approach aimed at providing a broad decision-making base to formulators of dairy feeds by employing the use of linear as well as non-linear programming (Dave, 2004). Specifically, the aim was to derive the best combination of ingredients, to realise the most economical dairy feed to maximise milk yield and profits while maintaining minimum P-excretion in manure. To ensure simplicity of the programming approach the model was based on MY and DMI thus:

$$MY = (0.4 + (0.15 * BF)) / FCM_{4\%} \qquad \text{Function 1,}$$

$$DMI = (-0.293 + 0.372 * FCM + 0.0968 * [BW.\mathrm{sup}.0.75]) * (1 - \exp(-0.192 * (WIM + 3.67))) \qquad \text{Function 2,}$$

predictive functions from the NRC (2001) and CP: P ratio and research observations where;

MY	=	Milk yield
FCM	=	Fat corrected milk
BF	=	Butter fat
DMI	=	Dry matter intake
$BW^{0.75}$	=	Metabolic body weight
WIM	=	Weeks in milk

These functions are used to rigorously map lactating dairy cow parameters (MY, LBW, BF) with a specific cow category in the core simulation model of NRC (2001) daily nutrient requirements of lactating cows and by extension connect them to the final user interface layer for user input data. Hence the basis for the start of formulation processes against some outlined daily nutrient requirement for a described cow.

Optimising multi-objective predictive functions

Specifications of a multi-objective programming approach necessitate target values for cost, milk yields, and excess nutrients objectives (Heard et al., 2004). The feed cost target, C, the milk yield target, M and the phosphorus target, P, were obtained through separate linear and non-linear programming models described by Morse et al. (1992), Varela-Alverez and Church (1998) and Tozer and Stokes (2001). Table 8 presents a summary of the formulation model activities and imposed constraints.

Table 8: Summary of the formulation model activities and imposed constraints

Activity	Model Function	Imposed Constraints
Feed quality	CP:P ratio	High CP:P ratio ingredients
Least cost feed	$\min \ C = \sum_{i=1}^{I} \pi_i X_i$	Minimum ingredient cost ($C X_i$)
Minimum P-excretion	$k(14.67 + 0.678\, p + 0.00196\, p^2 - 0.317\, m)$	Minimum nutrient excretion (P-level ≤ NRC values)

Source: Adapted from Waugh, (1951), Morse et al., (1992), and Tozer and Stokes, (2001)

Crude protein: phosphorous ratios and ingredient groupings

Typically, feed by-products are incorporated in dairy feeds because of their relatively high Energy (E), Crude Protein (CP) or Mineral (M) contents at cost-attractive market prices. However, some by-products contain high concentrations of P; with variable P-bioavailability (Adams, 1975). The primary objective of a dairy supplement is to provide protein, and not phosphorous. To achieve a good balance between feed quality and minimum nutrient P-excretion in manure, it is necessary to utilise protein sources with high crude protein (CP) to phosphorous (P_{av}) ratios as a selection criterion for inclusion of an ingredient in the final MoF-program formulation. Therefore, using ingredient by-products with higher CP: P_{av} ratio provides the much needed protein with less P; whilst continued utilisations of protein sources or ingredient by-products with lower CP: P_{av} ratios may even be more costly in the long-term (Dave, 2004). To simplify the formulation process, available concentrate ingredients are therefore categorised into three groups i.e. Energy (E); Protein (CP); and Minerals (M) rich concentrates as shown in Table 9; for their step-by-step nutrient contribution in calculating the ration totals. They are further coded using the letters E, CP and M and incorporated in the programs user defined formulation functions to improve on the formulation efficiency.

Table 9: Crude protein and phosphorous ratios and grouping of some ingredients

S/No	Ingredient	Ingredient Grouping	Must-include	CP %	P %	$CP:P_{av}$ ratio	Safe max
1	Dairy premix	M	X				0.5
2	Limestone	M	X				0.5
3	DCP	M	X				0.5
	Energy rich source(s)						
4	Wheat bran	E		15.15	0.92	16.46	20
5	Maize germ	E		10.53	0.53	19.87	30
	Protein rich source(s)						
6	sunflower seed cake meal	CP		26.88	0.57	47.16	8
7	Cotton seed cake meal	CP		29.29	0.62	47.24	15

Source: Adapted from Naku Modern-Feed Mill, Nakuru, Kenya, June to August, (2011)

Least cost function

The objective function specified by equation (1) depicts the summation of the prices of the i^{th} feed ingredients (π_i) multiplied by their proportional use (X_i) in the optimal feed. The minimum cost target C is expressed thus:

$$\min \quad C = \sum_{i=1}^{I} \pi_i X_i$$ Equation 1

The inclusion rate of every ingredient is subject to a safe minimum and safe maximum in order to guard against nutritional deficiencies and/or excesses. Equations (2) and (3) present typical nutritional upper and lower bound constraints of inclusion rates.

$$\sum_{i=1}^{I} a_{ij} X_i \geq b_j \forall J = 1,2,\ldots J-1$$ Equation 2

$$\sum_{i=1}^{I} a_{ij} X_i \leq b_j \qquad \text{Equation 3}$$

$$\sum_{i=1}^{I} a_{ij} X_i \leq J \qquad \text{Equation 4}$$

The technical coefficients a_{ij} measure the amount of the *j*th nutrient in the *i*th feed ingredient while the right hand sides, b_j, give the minimum or maximum amount of the *j*th nutrient allowable in the feed depending on the indicated sign of the inequality. There are a total of *I* feed ingredients and *J* nutrients and $j=J$ refers to dry matter (DM) as indicated by the constraint Equation (4); which is incorporated in the programming as a critical goal in feed formulation.

Minimum P-excretion function

Target phosphorous excretion, *P*, is found by minimizing a non-linear Function 3 by Morse et al. (1992) subject to Equations 2 and 3 above, and an equality relation that determines the optimal feed's total phosphorous intake. The non-linear function is expressed thus:

$$\min \quad p = k(14.67 + 0.678\ p + 0.00196\ p^2 - 0.317\ m) \qquad \text{Function 3}$$

Subject to equations 5 and 6;

$$\sum_{i=1}^{I} a_{ij} X_i = P \qquad \text{Equation 5}$$

$$\sum_{i=1}^{I} a_{ij} X_i \leq J \qquad \text{Equation 6}$$

Phosphorous excretion in manure is calculated using the equality relation (3) and is denoted by *p*. A summary of the program model notations is presented in Table 10.

Table 10: Summary of the model notations

Indices	Definition
i	Ingredient
j	Nutrient
Parameters	
π_m	Price of milk (Kshs/kg of milk)
π_i	Price of ingredients (Kshs/kg as fed)
a_{ij}	Amount of nutrients j in ingredients i (% or g/kg DM)
b_j	Required amount of nutrient j (%, kg, MCal)
k	Phosphorus intake efficiency (%)
C	Target feed cost (Kshs/cow/day)
M	Target milk production (kg/cow/day)
P	Target phosphorus excretion (kg/cow/day)
Variables	
X_i	Required level of ingredients i in feed (kg/cow/day)
Functions	
C (X_i)	Feed cost in Kenya shillings (Kshs/cow/day)
M (X_i)	Optimum Milk yield (kg/cow/day)
P (X_i)	Phosphorus excretion (kg/cow/day)

Source: Adapted from Waugh, (1951), Morse et al., (1992), and Tozer and Stokes, (2001)

4.2.4 Feed formulation process

Available ingredients and their nutritive values

The formulation of concentrate dairy feeds begins with the listing of available ingredients (Table 11) for uptake in the feed and presented in a schedule thus:

- Dry matter content (DM %)
- Total digestible nutrient (TDN %)
- Crude protein (CP %)
- Crude fibre (CF %)
- Neutral detergent fibre (NDF%)
- Calcium (Ca %)
- Phosphorous (P %)

- Phosphorous availability (P_{av} %)
- Protein: Phosphorous ratio
- Price per kg of ingredient
- Price per unit TDN %
- Price per unit CP %
- Safe minimum and maximum inclusion level (%)

Table 11: Nutritive values and unit prices of available ingredients in Nakuru (Kenya)

					Analysis (g kg of DM)				
Ingredients	DM %	TDN	CP	CF	NDF	Ca	P	P_{av}	Unit price/kg
Fish meal	89.50	67.55	48.73	11.27	3.00	0.17	0.75	X	58.00
Cotton meal	95.86	58.63	29.29	9.47	34.50	0.26	0.62	X	51.00
Sunflower meal	90.09	57.66	26.88	12.63	33.07	1.73	0.57	X	39.00
Maize germ	88.62	90.68	10.53	10.30	5.52	0.02	0.53	X	23.00
Wheat bran	91.80	60.76	15.15	5.22	12.17	0.09	0.92	X	17.50
Wheat pollard	88.75	75.82	13.96	3.80	5.87	0.18	0.55	X	23.50
Dairy premix	98	0	0	0	0	0.65	0.03	X	250.00
Limestone	100	0	0	0	0	15.87	0.08	X	60.00
DCP	97	0	0	0	0	13.43	5.08	X	80.00
Magadi soda	21	0	0	0	0	4.13	0.17	X	140
Molasses	75	71	2.3	0	0	0.42	1.36	X	350

Source: Adapted from Naku Modern-Feed Mill, Nakuru, Kenya, X = Dynamically computed

Fixing ingredient and nutrient constraints

Fixing of the TDN % and CP % levels is based on the nutritional analysis of the available ingredients (Bouwman, 1999). In fixing the safe minimum and maximum inclusion rates, the following feed factors were considered; toxic matters, influence on palatability, milk quality, digestive tract, and ingredient availability. The requirements of the feed (Table 12) to be composed are fixed under the following consideration:

- A minimum TDN % (considering prices per unit TDN)
- A minimum and maximum percentage of digestible crude protein
- A maximum percentage of crude fat
- A maximum percentage of calcium and maximum percentage of phosphorous

Table 12: Fixing ingredient and feed nutrient requirements constraints

S/No	Ingredient	Inclusion %	TDN	CP	P	CP:P ratio	Price/ TDN %	Price /CP %	Price/100kg	Safe min	Safe max
1	Dairy premix										
2	Limestone										
3	DCP										
4	Energy rich source(s)										
5	Protein rich source(s)										
	Sub-total	50%									
6		60%									
7		70%									
8		80%									
9		90%									
	Requirement Optimal range:	100%		Min: Max:			Min:				

Fixing formulation constraints

In composing the dairy feed proper, the following reserved inclusion proportions are considered in building the feed up to 50 percent level.

- About 1 to 4 % for the must inclusions of any dairy premixes, animal proteins and vitamin-mineral concentrates
- 30 % of ingredient(s) which are higher in TDN % than the required optimum level of the feed; specifically those ingredients that have the highest CP: P_{av} ratio and lowest price per percentage TDN, but no more that the safe maximum percentage.
- About 16 to 18 % of ingredient (s) which are higher in CP % than the required optimum level of the feed; specifically those ingredients that have the highest CP: P_{av} ratio and lowest price per percentage CP, but no more that the safe maximum percentage.

Having 50 % then, continue building further on step-by-step; adding 10 % at a time but within the safe maximum levels. At 50, 60, 70, 80, 90 and 100 %, always check for TDN and CP levels and select on the basis of 10 % ingredients which are balancing the feed and which have the highest CP: P_{av} ratios and cheapest.

4.2.5 Program technical validation process

The developed feed formulation software package was tested for technical as well as dynamic functionalities according to the Software Engineering Best Practices guidelines of (1998). Overall system technical functionality testing was performed to capture and correct errors before the final implementation. The field survey results as well as user feedbacks were used to perform model re-design and capability enhancements in readiness for the program operational validation under practical on-station condition at Ngongongeri Farm of Egerton University-Njoro, Kenya.

To perform technical program validation, users interact with the program by firstly registering with the system by providing necessary user details: name, contact address and farm number including; additional farm management variables needed for software program reports like the customer herd size (HS), milking times (MT), and prevailing market milk price (MP), after which an instance of each user profile is created. The system further requires users to select available ingredients from the ingredients DB, set appropriate ingredient and nutrient constraints, and provide cow production performance details upon which the formulation of a balanced multi-objective dairy diet is based. User data is entered through a VB form linked to the core simulation model; which automatically calculates and generates nutrient requirements for the particular cow or cow production groups under the specified constraints of a customer instance. The MoF-Dairy Edition program is equipped with powerful queries to calculate the dairy feed formula.

4.2.6 Program sensitivity analysis

An assessment process that compared the expected results with the possible results was performed. The assessment was benchmarked on the initial model base situation and then assumptions of the input values were estimated in the range of plus and minus 5 units. The aim was to subject the program into functional testing regimes by attempting to predict alternative outcomes of the same course of action. Specifically, ingredient prices, milk yields and milk prices were considered as the key input drivers of the model, while feed cost, milk profit margins and minimum p-excretion were the observable outputs as shown in Table 13**.** Results showed that the program is stable and responsive to different situations and thus could withstand rigorous system testing for comparison with other systems of a similar nature.

Table 13: Sensitivity analysis results

Key variables in the predictive functions	Sensitivity levels	Change values	Formulation goals			Deviation of ration nutritive values		
			Least cost feed (Kshs/Kg feed)	Milk profit (Kshs/Kg feed)	Minimum P excretion (g/Kg DM manure)	TDN %	CP %	P %
Ingredient price (Sunflower seed cake meal) (Kshs/Kg)	- 5 units change	34	23.78	19.42	4.27	0	0.96	- 0.04
	Base situation	39	23.26	19.31	4.29	0	0.77	0.00
	+ 5 units change	44	24.01	18.56	4.39	0	0.77	0.03
Milk yield (Kg)	- 5 units change	7	23.26	19.31	- 2.81	0	0.77	- 0.05
	Base situation	12	23.26	19.31	4.12	0	0.77	- 0.05
	+ 5 units change	17	24.53	18.67	- 6.32	0	0.77	- 0.05
Milk price (Kshs/Kg)	- 5 units change	23	23.26	11.71	4.12	0	0.77	- 0.05
	Base situation	28	23.26	19.31	4.12	0	0.77	- 0.05
	+ 5 units change	33	23.26	26.91	4.12	0	0.77	- 0.05

4.3. Results

4.3.1 Calculations by predictive functions

Milk yield and dry matter intake

The NRC (2001) MY and DMI modelling approach that recommends use of only animal factors that are measurable on an individual basis including; 4 % FCM rather than MY together with metabolic body weight ($BW^{0.75}$) rather than live body weight (LBW) and weeks in milk (WIM) were utilised in the MY and DMI Functions 1 and 2 respectively. Figure 6 illustrates data set for lactating Friesian cows from Egerton University's Ngongongeri Farm with the following production performance parameters: LBW = 400 kg; MY, 12 kg; BF = 3.61; and WIM = 10, from June 26th to August 22nd, 2011. These were used in the determination of the herd FCM and hence DMI.

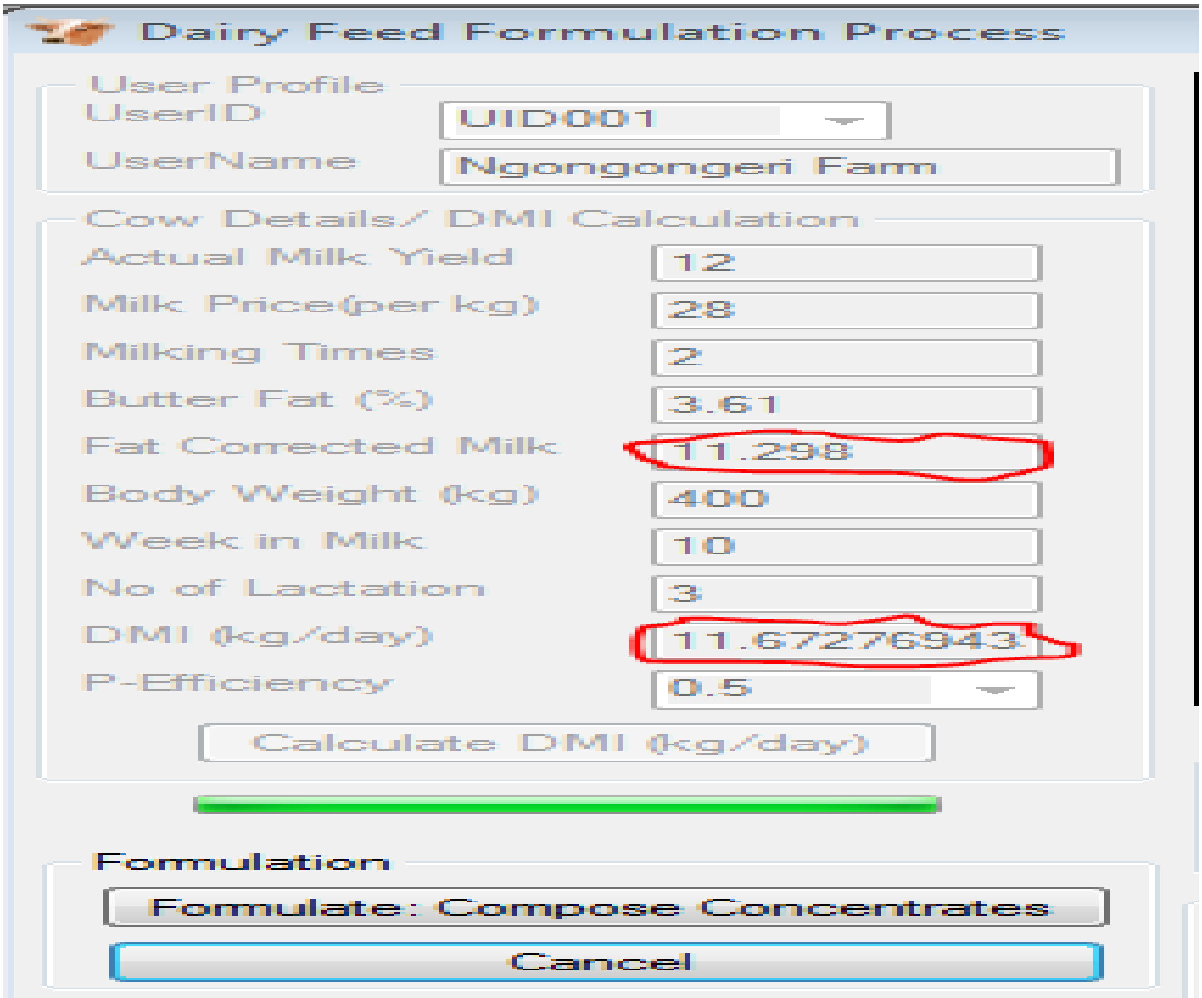

Figure 6: Predicted milk yield (4 % FCM) and daily dry matter intake DMI) in kg per day for Friesian cows in Ngongongeri Farm, Egerton University, Kenya

Summary of dairy cow formula with nutrient composition and cost price

Energy and Proteins are the most limiting nutrients to milk production under tropical dairy farming conditions (Bouwman, 1999). The developed dairy feed formulation program was designed to firstly satisfy the cheap energy requirements and then step-wise calculate for protein (CP) requrements and as such the formulated dairy feed quality calculations were therefore based on calculated ration totals (CRT) for protein values as shown in Table 14. One major assumption made in milk yield calculations is that production of 1 kg of milk of FCM requires 84 grams of CP (Bouwman, 1999; Muia et al., 2005). Thus a ration of X % CP content is equivalent to X g of CP per 100g on DM feed or (10Xg of CP per 1 kg DM feed) and hence the feed quality was calculated thus: ration protein value (10X g of CP) divided by 84 g of CP required to produce I kg of FCM milk-as per the on-farm experimetal diet.

Table 14: Summary of dairy cow formula with nutrient composition and cost price

Formulation

Summary of Ration Formulate

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Ingred_Name	%	DM	TDN	CP	RUP	RDP	CF	Ca	P	UnitPrice
Molasses	5.00	37.50	3.55	0.12	0.00	0.00	0.00	0.02	0.07	0.88
Magadi Soda	0.10	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
DCP	0.10	0.97	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.08
Limestone	0.10	1.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01
Dairy Premix	0.50	4.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25
Wheat Pollard	10.00	88.75	7.59	1.40	0.00	0.00	0.38	0.02	0.06	2.35
Wheat Bran	20.00	183.60	12.15	3.03	0.00	0.00	1.04	0.02	0.18	3.50
Maize Germ	10.00	88.62	9.07	1.05	0.00	0.00	1.03	0.00	0.05	2.30
Maize Germ	20.00	177.24	18.14	2.11	0.00	0.00	2.06	0.00	0.11	4.60
Sunflower Meal	5.73	51.62	3.36	1.54	0.00	0.00	0.72	0.10	0.03	0.52
Cotton Meal	1.00	9.59	0.59	0.29	0.00	0.00	0.09	0.00	0.01	0.51
Cotton Meal	14.00	134.20	8.21	4.10	0.00	0.00	1.33	0.04	0.09	7.14
Fish Meal	0.50	4.48	0.34	0.24	0.00	0.00	0.06	0.00	0.00	0.29
Fillers	12.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ration Totals	100.00	782.68	63.00	13.88	0.00	0.00	6.71	0.23	0.61	Ksh. 23.44

Note: UID001 = User Identification Number One; 13 = Report Sample Run Number

Supplementation levels

Lactating dairy cattle supplementation levels are majorly dependent on the difference between potential (PMY) and actual (AMY) daily milk yield (denoted by: Y kg of milk per day), roughage quality and concentrates feed quality based on the most limiting nutrient to milk production (CP % content) as well as the number of cow milking times per day (MoLD, 1995). The resultant calculation for instance, assuming 2 milking times per day on average using concentrate feed quality of (10X/84 kg of milk per kg feed) was calculated thus:

$(Y * (^{10}X/_{84})) \div 2$: gives the number of kg of supplement feed per milking.

Marginal milk profits

In the formulation of a diet, the objective is to maximise the difference between the income from milk and the expense on feeds. Since the formulation was on DM basis, the prices of the feedstuffs were converted from as fed basis into DM basis. The product was achieved by dividing as fed price by DM % for each feedstuff. Total income from milk minus total expense on feed, where: Optimal milk yield/cow/day (M) multiplied by the price per kg of milk (π_m) calculated the total income ($M\pi_m$), and price/kg DM feedstuff π_i multiplied by amount of consumed supplement feed per cow per day in kg (X_n) calculated the total expense on concentrate feed per day ($X_n \pi_i$); hence the Maximum milk profit function ($M\pi_m - X_n \pi_i$) was derived. Table 15 presents milk profit margins which were determined by calculating the total revenue from milk sales (extra kg of milk (Y) by market milk price (Kshs 28) minus total supplementary feed cost; (10XY/84 by cost of kg commercial feed Kshs 23.44).

Table 15: Milk profit margin calculations

Profit Margin		
	per Kg of Feed	Ksh. 22.83
	per Cow	Ksh. 13.81
	per Herd	Ksh. 165.77

Minimum P-excretion in manure

Under normal conditions, urinary P excretion is negligible and, therefore, the P-manure balance of dairy cows (Function 3) is determined by P intake, intestinal absorption and secretion in milk. Milk P output is directly related to milk yield, since milk P concentration is constant (NRC, 2001; Valk and Beynen, 2002; Valk et al., 2002). The optimised minimum P-excretion Function 3: where; k is the efficiency of phosphorous digestibility which ranges from (0.1, 0.2 …0.5, 0.6, 0.7, 0.8, 0.9, 1.0); *p* is the value of formulated feed phosphorous per kg DM feed (e.g. F % *P* is equivalent to 10F g of phosphorous per kg DM feed). Meaning that for a cow supplemented at (Read as Daily Total in the program report analysis, X kg of feed per day, then the value of P above would be calculated thus: (10 F g of *P* per kg DM feed * X kg feed) equals 10FXg of *P* on DM basis per day. Consequently the value of p^2 was $(10FX * 10FX)^2$ equals $(100FFXX)^2$ g of *P* on DM basis. The value of *m* is the total potential milk production per day (PMY) in the program and since, 1 kg milk contains 0.9 g of *p* (Morse et al., 1992; NRC, 2001; Dave, 2004), (standard and constant) a cow whose PMY of say (Y_{max} kg of milk per day), (from the average of experimental lactating cows), then the total *P* content in her milk would be given by (0.9 g per kg milk * PMY), hence the value of *m* in the equation was dynamically substituted thus: (0.9 g of *P* * Y_{max} kg of milk per day) on DM basis. Finally, the excreted P-manure value was converted from on dry matter (DM) basis into on fresh matter (FM) basis to reflect real farm feeding situations and manure excretion in published as well as regulatory values, termed ("dilution factor"). Given that the formulated feed (CRT) DM value of W g per kg feed, then on FM matter basis, the value of minimum *P* was given by (0.9 g per kg milk * PMY * W g per kg feed) g of excess P-manure per day on FM basis. The resultant DM and FM basis *P* values were thus compared with published literature (5 g /kg DM manure) as well as regulatory standard (30 mg/Litre of waste effluent) values (Table 16) for effluent discharge into public sewers of maximum permissible level as stipulated in EMCA, (2006) guidelines. The P availability used to calculate the dietary requirement was from the sample lactating cow diet included in the software.

Table 16: Potential excess P-manure excretion into the environment from Ngongongeri Farm

Gross Environmental Components

Predicted P-Manure (g/kg)		Recommendations		P-Pollution (g/kg)	
Dry Matter	Fresh Matter	Literature Value	Nema Standards	Dry Matter	Fresh Matter
11.15	8.72	5 g/kg DM	30 mg/kg FM	6.15	8.69

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4.4 Discussion

4.4.1 Incorporation of milk yield, dry matter intake and P-manure predictive functions

While feed formulation models are useful tools to aid decision-making in feed manufacturing, there remain several types of uncertainty associated with this method of analysis. One-way sensitivity analysis allows reviewers to assess the impact that changes in a certain parameter will have on the model's outputs. Sensitivity analysis can help the reviewers to determine which parameters are the key drivers of a model's results. By reporting extensive outputs from sensitivity analysis, modellers are able to consider a wide range of scenarios and, as such, can increase the level of confidence that reviewers will have in the model.

Prediction of feed intake by dairy cattle has received much attention for many decades, and numerous models (Brown and Chandler, 1978; Waldner, 2003; Thorne and Dijkman, 2005; Concepcion et al., 2006) have been developed. The traditional motivation for this interest is that providing a balanced diet increases production, efficiency, and profitability (Shah and Murphy, 2005) of dairy enterprises. Prediction of feed intake by lactating cows usually depends on knowing what sort of feeds they are consuming. The MY, DMI and P-manure prediction models used in the proposed multiple objectives diet formulation are represented by Functions 1, 2, and 3. These functions do, however, provide a strong base upon which a computerised multiple ration formulation program can be built. They are particularly important when cost of extra feed is being balanced against projected returns from additional milk yields and the ability of the cow to consume extra feed in a ration for maximum profit; while guarding against excessive pollutant nutrients from manure into the environment.

4.4.2 Feed quality

Feed cost accounts for about 40-70 % of dairy production costs in highly intensive dairy systems (Jones et al 1980; MoLD, 1995; Muriuki 2006; MoLFD 2007; LPEM, 2008). However, concerns over the quality of cattle feeds have persisted (Mbugua, 1999; Staal et al., 2003; Muriuki, 2006), this is probably the reason why producers often attribute variable milk quantities and quality to variations in feed quality. From the perspective of the dairy producer, quality of feed may be as important as cost (Technical Team, 2006; AKEFEMA, 2008; MoLD, 2009). Variable and unreliable feed quality increase risks and costs, and may dissuade prospective entrepreneurs from undertaking intensive dairy production strategies. Variable feed quality may also affect smallholder producers more severely than others. In such conditions, large producers who can invest in their own feed ration formulation may be able to gain a competitive edge over smallholders, who rely entirely on available market supply of commercial feeds of variable quality (Mbugua, 1999; Muriuki, 2003). The quality problem is partially affected by low supply of the necessary ingredients, especially those that are not locally available, such as oil-seed cakes and meals, meat and bone meal, fish meals, premixes, and mineral, vitamins and amino acids concentrates (Muriuki et al., 2003); and also partially by the least-cost formulation approach commonly implemented by feed millers in Kenya. Nonetheless, the MoF-Dairy Edition program potentially offers a solution since it optimises cost, production and policy regulatory frameworks step-wise by integrating the three functions respectively.

4.4.3 Prediction of dry matter intake and milk yield

The positive relationship between feed intake and milk yield where, milk production increases as feed intake increased though at a progressively diminishing rate has been described (Andrés and Carlos, 2006). Several approaches to modelling DMI exist, including mathematical models (Nagorcka, et al., 2004), of ruminal function; the weekly average intake of a group or the daily intake of an individual cow as advanced by various international research bodies like Agricultural Research Council (ARC), Cornell Net Carbohydrate and Protein System (CNCPS), Agriculture and Food Research Council (AFRC)and NRC, 2001; Jensen et al., 1942; MoLD, 1995; Mbugua, 1999; Muriuki, 2006; McEvoy et al., 2008). However, the NRC is regarded as the "bench mark" model and even where individual states or regional blocks have established their own specific models, they have always used NRC for comparison. Ironically, the NRC model was last updated in 2001, despite recent tremendous achievements by many individual research groups in the field of dairy cow nutrition and feeding; and the precision to predicting DMI and hence MY.

The voluntary DMI of the dairy cow is an important variable in dairy management since it fosters nutritional and economical accuracy in ration formulation. Together with MY, it can be used to estimate the economic value of an individual cow at any given stage of lactation and hence improve economic decisions of whole farm operations. The variable becomes crucial for nutritional reasons, especially when concentrates are formulated for either supplementary or total mixed rations (TMR) for dairy cows. Lack of accuracy in prediction may result in nutrient underfeeding or overfeeding thus affecting animal performance, animal health or dairy farm environment. Feed intake prediction inaccuracy may also limit (Hristov et al., 2004; Hristov, et al., 2005), the ability of different simulation and optimization techniques to improve the business and technical efficiency of key operations in dairy farms such as feeding, breeding, or replacement.

4.4.4 Prediction of minimum phosphorous excretion

The level of P found in feeds used in dairy cattle rations is quite variable. Adams (1975) reported a 10.6 fold range in the P content of legume-grass forage-concentrate samples. The availability of P in mineral sources has been examined in a number of trials (Jackson et al., 1988; Macro-minerals, 1995). Mono-ammonium phosphate and Di-calcium phosphate had similar biological availabilities when used in rations for growing bull calves (Jackson et al., 1988). A recent summary indicated that the biological availability of monosodium phosphate, mono-ammonium phosphate, sodium tri-polyphosphate and Di-ammonium phosphate were all in the range of 95 to 100% (Macro-minerals, 1995). Similar values for Mono-calcium phosphate, Di-calcium phosphate, De-fluorinated phosphate, steamed bone meal, fish meal, and soft rock phosphate were 95-98, 93-95, 88-91, 80-82, 90-95 and 25-35% respectively.

The underlying assumption of the current study is that inclusion levels of P in dairy rations affect the inorganic phosphate (P_2O_5) content of manure excreted by lactating cows. Published results (Lekasi et al, 2001a; Ayako,, 2005) only report one value for P_2O_5 content of manure excreted (5 g/kg DM manure) and do not specify the phosphorus levels in the rations used to compile the data. Therefore, calculated values of P-excretion for lactating cows were used rather than the P_2O_5 results from published sources to better account for the varying levels of P inclusion in rations. The MoF-Dairy Edition program calculated P-manure was 11.15 g/kg DM manure resulting in predicted potential excess P-manure of 6.15 g/kg DM basis. Past literature has demonstrated the most accurate way to account for P-excreted in manure for lactating cows is subtracting the amount of P in milk produced from the amount of ration P (Morse et al., 1992; Lara, 1993; Wu, et al., 2003).

4.5 Conclusion

The design and development of the proposed MoF-Dairy Edition program has been able to follow the multiple objectives feed formulation approach that attempts to optimise business, production as well as policy regulatory goals of industry actors. The MoF-Dairy Edition program has demonstrated the capability of generating reports on dairy feed formulae with unit cost, nutrient variation, calculated P-manure potential environmental pollution as well business economic analysis at supplementation with feeds of known quality. Consequently, the program can be used as a feed planning and decision-making tool for the day to day running of the fast growing feed industry with regard to policy formulation and regulatory frameworks.

CHAPTER FIVE

COMPARISON OF LEAST-COST AND MULTI-OBJECTIVE DAIRY FEED FORMULATION PROGRAMS: FEEDING TRIAL VALIDATION RESULTS

Abstract

An experiment was undertaken to compare MY, MC and excess manure P level at supplementary feeding of lactating cows fed LCF and MOF concentrate feeds formulated using two software programs. Twelve lactating dairy cows of the same age, breed and parity were randomly assigned across two treatments in a crossover repeated measures design with six replications each for 70 days from June 26th through 22nd August 2011. The two animal groups were offered a common DHA predominantly composed of Rhodes grass (*Chloris gayana*) and placed under 2 types of concentrates (LCF and MOF) for two periods (P_I and P_{II}) of 28 days each with 14 days adaptation phase. Concentrates were offered in the milking parlour in two equal feeds at the morning and evening milking. Offering concentrate increased mean milk yield by 1.35 kg/cow/day (LCF) and 1.39 kg/cow/day (MOF) up from the herds' average yield of 12 kg/cow/day. Cows supplemented with MOF feed concentrate significantly ($p < 0.05$) produced more milk (0.04 kg/cow/day) than LCF treatment. Milk butter fat concentration increased with concentrate type, as did milk protein and milk phosphorous (P-milk). Milk from cows on MOF treatment had a significantly ($p < 0.10$) higher fat concentration (2.60 g/kg) than milk from cows offered LCF treatment (1.50 g/kg). Milk protein yield was significantly ($p < 0.05$) higher among animals offered LCF (0.24 g/cow/day) than MOF (0.22 g/cow/day) concentrates. Milk-P concentration was significantly high ($p < 0.05$) under MOF (0.16 g/cow/day) compared with LCF (0.13 g/cow/day). Manure-P excretion was significantly ($p < 0.05$) higher under LCF (1.71 g/kg DM manure) than MOF (1.66 g/kg DM manure). There was no significant increase in mean LBW when LCF (430.60 kg) and MOF (425.70 kg) concentrate types were offered. The MOF feeding regime resulted in higher milk yield and better milk composition as well as lower manure-P content than LCF.

Key words: feed formulation programs, milk yields and composition, manure P excretion

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5.1 Introduction

In Kenya, milk is traditionally produced at the lowest possible cost from a pastures and crop residues-based feeding system. The price of milk has been low and constantly fluctuates with seasons. However, since mid-2002 milk market prices have been rising steadily, and there has been a tendency to move from pastoral milk production to more intensive systems (Muriuki et al., 2003; Muriuki, 2006; MoLFD, 2006a; MoLD, 2007) where commercial dairy concentrates are fed as supplements. In situations where the price of milk is constantly increasing, it may be difficult to estimate where the cost of additional feed ceases to generate extra milk income. Under such circumstances, the least-cost feed formulation paradigm becomes inadequate (Varela-Alverez and Church, 1998); since dairy feed formulation based on the singular objective of least cost feeds does not take into account the changing external circumstances in dairy farming facing the modern dairy producers, particularly the seasonality of milk market prices and growing environmental pollution concerns. Additionally, the least cost formulation approach only satisfies millers' objective of minimising feed costs and hence maximising manufacturing profits. Consequently, this formulation method does not incorporate the objectives of dairy producers of maximising income above the market price of feed at the prevailing milk prices and the governments' objective of limiting the excretion of excessive pollutant nutrients from dairy enterprises into the environment.

Milk market prices in Kenya are seasonal (Muriuki et al., 2003; Muriuki, 2006). During the rainy season when good quality pastures are plenty and milk yields are high, dairy farm milk prices are low. On the contrary, during the dry season when good quality pastures are scarce and milk yields are low, dairy producers fetch high milk prices. Therefore, dairy producers intending to benefit from such high dry season milk prices need to supplement their cows with good quality dairy meals. In their attempts to do so chances of environmental P-manure pollution exist (Morse et al., 1992); since available formulation programs do not address minimum P-levels in dairy feeds as a critical formulation goal (Concepcion, 2006). To ensure strict adherence to emerging global environmental regulatory limits while maximising milk yields, it is necessary to rely on feeds based on multiple objectives formulation functions approach (Tozer and Stokes, 2001). Utilization of MoF dairy feeds potentially offers a solution to maximise milk yields and profits and reduce the excretion of excess P in manure in conjunction with the singular objective of least cost feeds (Varela-Alverez and Church, 1998; Tozer and Stokes, 2001). Currently, there is no comprehensive data and information regarding the comparison of milk production performance and excess P manure levels from lactating dairy cows supplemented with least-cost (LCF) and multi-objective (MOF) concentrate feeds, since such a study has not been conducted in Kenya.

Often computer feeding models are developed for practical application but are rarely tested under field conditions. To address challenges among dairy enterprises practicing concentrate feeding, a comprehensive study of milk production performance and excess nutrients in manure at supplementary feeding using LCF and MOF models becomes important. The possible comparison between milk yield and excess P excretion in manure among lactating cows fed LCF and MOF concentrates has not been examined in earlier studies on dairy cows supplementary feeding (Mbugua, 1999; Lekasi et al., 2001a and b; Muriuki, et al., 2003; Ayako, 2005; Muriuki, 2006). The objective of the current study was to evaluate the performance of lactating dairy cows subjected to LCF and MoF diets under practical on-station trials.

5.2 Materials and methods

5.2.1 Study site

The experiment was conducted at Ngongongeri Farm of Egerton University, Njoro, Kenya, within the Rift-Valley (0^0 40' S, 36^0 26' E; 1900 M above sea levels) from 26^{th} June through 22^{nd} August 2011. The mean-annual rainfall for the study site is 1060 mm with mean annual temperature of 16^0 C; specifically, during the study period the total rainfall was 1537 mm with mean temperature of 18^0 C. The soils are dark grey-dark brown with humic top-soil and are very deep and slightly-moderately alkaline (Jaetzold and Schimdt, 1983; KARI-Njoro, 2011).

5.2.2 Experimental design and animals management

Treatments

The experiment investigated the effect of offering two types of formulated concentrates in a crossover repeated measures design with two periods. Twelve Friesian dairy cows were selected from Ngongongeri Farm of Egerton University-Njoro, Kenya; dairy milking herd and balanced for initial LBW (422, SD 40.94), WIM (13.42, SD 4.68), and MY (12.09, SD 2.34). Animals were then randomly assigned to 1 of the 2 feeding treatments for 70 days. The basic crossover repeated measures experimental trial was defined by two treatments (LCF and MOF) which were under study, where each animal (lactating dairy cow, experimental unit) received both treatments in either of the sequences LCF, MOF or MOF, LCF. The twelve experimental units (six lactating cows per treatment); used in the experiment were randomly allocated to the two sequence groups using the random number generator table. The crossover design exploited the fact that in each time period both treatments were administered; hence comparisons between treatments were free of period effects. Likewise, each animal received both treatments, so the comparison of treatments was within animals, thereby removing between-animal variation from the treatment differences.

Animal Management

Twelve Friesian lactating cows at 3rd parity were selected for the feeding trials. Prior to the allocation to the treatments, all the experimental cows were de-wormed two weeks in advance using Valbazen 10 % (ALBENDAZOLE). The two animal groups were offered a common daily herbage allowance (DHA) predominantly composed of Rhodes grass (*Chloris gayana*) and placed under 2 types of experimental concentrates (LCF and MOF); supplemented at 4 kg per cow per day for the two periods (P_I and P_{II}) as shown in Table 17. Concentrates were offered in the milking parlour in two equal feeds at the evening and morning milking. Prior to commencing the experiment, all dairy cows were offered the same diet consisting of Rhodes grass for 14 days at the start of period I as well as at the point of cross over to period II to allow for feed adaptations. Animals were allowed unlimited access to water daily and animal welfare was considered.

Table 17: Experimental design and concentrate feeding regimes

Experimental Period	Treatments	
1	LCF	MOF
2	MOF	LCF

Note: LCF = least Cost Feed; MOF = Multi-Objective Feed; Rhodes grass, the basal diet

5.2.3 Concentrate formulation

The concentrates were compounded from the same batch of ingredients sourced from the same feed miller, who maintained consistency in ingredient sourcing throughout the study duration. The concentrate was formulated based on the two feed formulation programs. The LCF concentrate was based on the least-cost (singular objective) approach using a LC-program ***Labelled® (1999***)-Version and the MOF concentrate was based on the proposed multiple objective approach using ***MoF-Dairy Edition® (2010)***-feed formulation program trial version.

5.2.4 Herbage, ingredients and concentrate feeds sample chemical analysis

Samples of Rhodes grass, ingredient used in the formulation of trial concentrates as well as the LCF and MOF formulated concentrate feeds (Tables 18 and 19) were collected randomly weekly during the study period, and analysed for dry matter (DM), total digestible nutrients (TDN)/Energy, crude protein (CP), crude fibre (CF), neutral detergent fibre (NDF), acid detergent fibre (ADF) and ASH (calcium and phosphorous) content using wet chemistry according to AOAC, (1995) and Near Infrared Spectroscopy (NIRS) according to Roberts et al., (2004).

Table 18: Chemical composition of Rhodes grass fed to experimental cows

Nutritive values	Rhodes grass DHA
DM %	90.90 ± 0.898
Analysis (g/kg of DM)	
TDN	282.00 ± 2.302
CP	90.30 ± 0.469
ADF	332.20 ± 0.772
NDF	663.20 ± 1.486
ADL	53.00 ± 0.570
Ash	81.40 ± 0.547

DHA = Daily herbage allowance, SD = Standard deviation

A total of 1, 344 kgs (4kgs for 12 cows for 4 weeks) of concentrate feed were blended into two equal halves and formulated into LCF and MOF supplementary diets while observing minimum and maximum inclusion levels for each concentrate mix.

Table 19: Chemical composition of concentrates formulated using LCF and MOF programs at Naku-Modern Feed Mill-Nakuru, Kenya

	Concentrate type	
	LCF	MOF
Nutrients	Mean Nutritive Value	Mean Nutritive Value
DM %	89.22 ± 0.181	78.15 ± 0.247
Analysis (g/kg of DM)		
TDN	634.00 ± 0.320	631.00 ± 0.224
CP	146.20 ± 0.296	138.80 ± 0.239
CF	123.50 ± 0.290	65.60 ± 0.314
P	6.35 ± 0.016	6.10 ± 0.004
Ca	5.80 ± 0.033	2.30 ± 0.019
CP:P ratio	23.02	22.75

LCF = Least cost feed; MOF = Multiple objective feed; SD = Standard deviation

5.2.5 Animal measurements

Milk yields and composition

Milking took place at 0600 hours and 1500 hours daily for 56 days. Individual milk yields (kg) were recorded at each milking. Milk composition (butter fat (BF), milk protein (MP), and phosphorous milk (P-milk)) were determined weekly from one successive evening (Sunday) and morning (Monday) milking samples for each animal using MilkScan/Analyser (European Make-2000). Continuous LBW changes between the two cow groups were monitored using the measuring tape converter.

Manure P nutrient analysis

Manure samples were collected at 0600 hours and 1500 hours weekly from one successive evening (Sunday) and morning (Monday) during milking session for each animal and analysed using NIR method as described by Roberts, et al (2004) to determine manure P levels (faecal only).

5.2.6 Statistical analysis

Milk yield, milk composition and Phosphorous manure content

The experiment investigated the effect of offering two types of formulated concentrate diets on two lactating cow groups for two periods in a crossover repeated measures design. The Linear model for the experimental trial was thus:

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

Where:

Y_{ij}	=	Overall cow performance under the i^{th} diet
μ	=	the overall mean effect
α_i	=	the effect of the i^{th} diet (i = LCF and MOF)
e_{ij}	=	the random error

Model parameters included; the mean (μ), the effect of the treatment (α_i), and the random residual variation (e_{ij}). Variation in LBW and WIM were adjusted for by fitting them as covariates in a (One-way (no Blocking) ANOVA) using GenStat Discovery Edition-3 statistical software (2007); which was used to process MY, BF, MP, and P-milk as well as manure-P contents data. All experimental cows survived throughout the study period.

5.3 Results

5.3.1 Milk yield and composition

Table 21 outlines milk yield and composition as well as milk-P and LBW change data throughout the study period. The type of supplement offered had a significant effect on milk yield ($p < 0.05$), milk butter fat ($p < 0.10$), milk protein ($p < 0.05$), milk-P ($p < 0.05$) and manure-P ($p < 0.05$) levels. There was a positive response in milk yield to concentrate type. Offering concentrate increased mean milk yield by 1.35 kg/cow/day (LCF) and 1.39 kg/cow/day (MOF) up from the herds' average yield of 12 kg/cow/day. Cows supplemented with MOF feed concentrate significantly ($p < 0.05$) produced more milk (0.04 kg/cow/day) than LCF treatment. Milk butter fat concentration increased with concentrate type, as did milk protein and milk-P. Milk from cows on MOF treatment had a significantly ($p < 0.10$) higher fat concentration (2.60 g/kg) than milk from cows offered LCF treatment (1.50 g/kg). Milk protein yield was significantly ($p < 0.05$) higher among animals offered LCF (0.24 g/cow/day) than MOF (0.22 g/cow/day) concentrates.

5.3.2 Manure phosphorous levels

The milk-P concentration was significantly high ($p < 0.05$) under MOF (0.16 g/Kg Milk) compared with LCF (0.13 g/ Kg Milk). Manure-P excretion was significantly ($p < 0.05$) higher under LCF (1.71 g/kg DM manure) than MOF (1.66 g/kg DM manure). There was no significant increase in mean LBW when LCF (430.60 kg) or MOF (425.70 kg) concentrate types were offered as shown in Table 20.

Table 20: Effect of concentrate type on milk yield, milk composition, manure P levels and Live Body Weight changes of lactating dairy cows at Ngongongeri, Njoro (Kenya)

	Concentrate diet type		
	Herds average	LCF	MOF
Yield (kg/day)			
Actual Milk	12.00	13.35 ± 4.695	13.39 ± 4.483
Milk Composition (%)			
Butter fat	3.760	3.914 ± 0.098	4.019 ± 0.165
Protein	3.135	3.154 ± 0.022	3.152 ± 0.033
Phosphorous	0.081	0.148 ± 00	0.151 ± 0.009
Manure Composition (%)			
P-Manure	0.609	1.71 ± 00	1.66 ± 0.026
Body Weight			
Mean (kg)	420	430.60 ±10.99	425.70 ± 8.770
Change (kg/day)		0.225 ±0.108	0.207 ± 0.108
Others			
Concentrate efficiency	-	0.34	0.35
Crude protein: Phosphorous ratio	-	23.02	22.75
Cost price/kg feed (Kenya shillings) 1USD ≡ 100 Kshs	-	30.38	23.44

LCF =Least cost feed; MOF =Multiple objective feed; SED =Standard error of the difference

5.4 Discussion

Meeting the daily feed and nutrient requirements of lactating cows using roughages alone presents a challenge. Even in the optimal scenario, herbage supply and nutrient availability are still limited on a seasonal basis, which leaves a requirement to further increase the nutrient levels in the diets of lactating cows during such periods. Additionally, feeding roughages and concentrates results in high feed costs and also presents the potential for environmental pollution from excess P-manure (Morse et al., 1992; Chase, 1994a; Knowlton, 1998; Mbugua, 1999).

In the current study, the concentrate efficiency, expressed in kg milk per kg concentrate feed intake, was systematically modest for LCF (0.34) and MOF (0.35), Table 20, at 4 kg concentrate levels for each regime. Though energy levels were similar for LCF and MOF, the diets varied in protein levels (14.62 %) and (13.88 %) and phosphorous content (0.635 %) and (0.610 %) respectively.

In recent years, computer formulation models have been developed for practical application but are rarely tested under field feeding conditions. Despite these advances, the question remains: can offering LCF or MOF supplementary feeds increase milk yield and result in better milk composition while minimising excess manure-P excretion? The results of the performance of lactating dairy cows supplemented with LCF and MOF concentrates under on-farm feeding trials are discussed.

5.4.1 Body weight change

Although not significant, supplementing cows with LCF concentrates increased LBW (+10.60 kg) and MOF (+5.70 kg) and generally reduced LBW loss, a finding similar to that of previous authors (Mbugua, 1999; Dillon et al., 2002; Kennedy et al., 2007). Since all the experimental cows were offered the same DHA ad-libitum, it can be deduced that any body weight change was majorly due to concentrate type. The fact that LCF concentrate contained more protein (0.74 g CP/kg feed) than MOF could have contributed to the observed high positive change in LBW for cows under LCF feeding regime. The excess protein supply in LCF diet above the recommended daily requirement could have contributed to the increased body weight; a common cause of low income over feed costs (IOFC) among dairy producers in Kenya (Mbugua, 1999; Muriuki, et al., 2003).

5.4.2 Effect of concentrate type on milk yield and composition

There are various factors which affect milk yield and fat content. However, dietary factors (Sawal and Kurar, 1998), with the highest influence include; the plane of nutrition, concentrate to forage ratio, level and sources of protein, fat, fibre and structure of diet. Different feeds result in variable types of fermentation in the rumen. The most important effect is seen on the volatile fatty acids (VFA) concentrations and proportions. From literature review, it became apparent that the higher the VFA concentration, the higher is the milk yield (Stockdale, 2000; Kennedy et al., 2005; Morrison and Patterson, 2007). Specifically, high propionate proportion has been related positively with milk yield, whereas the proportion of acetate and butyrate has been positively related with milk fat content. Dietary fat increases energy intake, production of milk and milk fat; and it can be included in the range of 3.5-5% to increase energy intake. A minimum of 17 % CF or 22 % ADF or 28 % NDF has been recommended below which there is depression in milk fat (Sawal and Kurar, 1998; Stockdale, 2000). The experimental common DHA provided 33.62 % ADF hence the observed high milk fat content in MOF was due to concentrate type and composition.

Dietary carbohydrates through the source of sugar, starch, roughage and fibre affect VFA concentration in the rumen. In the present study, there was marked increase in milk production when cows had access to both LCF (11.25 %) and MOF (11.58 %) dairy concentrates; this is similar to increases reported previously. The increase in milk production would be expected as a result of the large increase in DM intake. Similar increase in MY was recorded in 1993 and 1994, respectively, at similar levels of concentrate supplementation (Sayers et al., 2000).

Milk fat concentration was influenced by concentrate type; where supplementing cows with LCF and MOF concentrates resulted in increased fat concentration by 1.5 g/kg and 2.6 g/kg respectively. However, the MOF feed significantly yielded more milk fat (0.105 g/kg) than LCF. Although these findings disagree with early-lactation studies by Dillion et al., (2002) and Kennedy et al., (2007), it is in agreement with mid-lactation studies (Delaby et al., 2001) where animals were supplemented with greater than 5kg/cow/day of concentrate, possibly because of a dilution effect of milk yield increasing more rapidly than milk fat when concentrate was introduced into diet. Consequently, the fact that MOF feeding regime yielded more milk as well as higher fat content clearly demonstrated the superiority of MoF formulation approach over LCF approach.

The low proportion of concentrate in the diet is unlikely to have significantly affected the overall diet degradability or digestion of the diet as previously shown with in situ studies

(Dillion et al., 2002; Kennedy et al., 2005). Indeed, a review of literature indicates that the effect of concentrate type on milk fat concentration is only evident when concentrate inclusion level is above 50 % of the diet (Delaby et al., 2001; Kennedy et al., 2007). In the current study, the proportion of concentrate in the diet was about 10 % of total DM intake. Contrary, cows on the MOF treatment had a significantly higher milk fat concentration compared with cows on the LCF treatment pointing to the suggestion that the supplement composition affected rumen functioning.

High level of dietary protein improves DM intake and milk production, however, CP levels above the cows daily requirements present deleterious effects. The experimental diets contained CP levels at LCF (14.62 %) and MOF (13.88 %) against a daily requirement of 13 % CP. Milk protein concentration was influenced by concentrate type; where concentrate supplementation produced LCF (+0.24 g/kg) and MOF (+0.22 g/kg) of milk protein. The LCF concentrate contained more protein (0.74 g CP/kg feed) than MOF which may have been utilised in milk protein bio-synthesis as shown in Table 19. High dietary protein supply alters milk production due to effects on ration digestibility and DM intake; whereas maximum responses are achieved at around the recommended CP levels (NRC, 2001), above which there is small but declining rate of increase in milk yield. Experimental results showed that although MOF concentrate had less protein by 0.74 g/kg feed and of lower price by (Kshs 6.94), cows under MOF feeding regime registered higher MY than LCF, hence the calculated concentrate efficiencies of LCF (0.34) and MOF (0.35) attributed to energy-protein balance of the MOF concentrate are realistic. On a cost-benefit analysis basis, the current study demonstrated that feeding MOF concentrates resulted in high MY at a lower feed cost. Milk protein concentration and the composition of the milk protein was affected by supplement type in the present study with treatment MOF having a lower milk protein concentration by 0.033 g kg milk compared with treatment LCF. Milk protein concentration increases with increasing energy intake (Kennedy et al., 2005, 2007). The two concentrate diets contained the same amount of energy but varied in protein content; suggesting that milk protein concentration differences could only have been occasioned by concentrate type protein content.

5.4.3 Effect of concentrate type on phosphorous excretion from dairy farms

A number of papers have examined the relationships which exist between P intake and excretion in dairy cattle (Harris et al., 1992; Morse et al., 1992; Chase, 1994a and b; Morse et al., 1992; Lekasi et al., 2001a and b). Chandler (1996) indicated that P accounts for more than 50% of the cost of typical vitamin mineral mixes used on dairy farms. Thus, there is rationale from both business and environmental considerations to minimize feeding P in excess of requirements. It has been demonstrated (Chase, 1994a and b) that for a lactating cow, averaging 9,100 kg milk over 305 days, is fed a diet of 3.8 g P/kg of dietary dry matter (DM), approximately 0.71 ha or 1.75 acres of cropland (mixed alfalfa/corn/soybean cropping system) is needed to recycle the manure P excreted. In the present study, experimental cows averaging 3, 660 kg milk over 305 days were fed 3.175 g/P kg feed (LCF) and 3.05 g/P kg feed (MOF). Thus resulting in excess 0.026 g P/kg DM excreted in manure from cows fed LCF concentrate. Consequently, it would require 0.13 acres of cropland to recycle the excess manure P excreted by cows fed LCF than MOF concentrates. Considering production only, a kg of DCP costs approximately Kshs 90. Therefore feeding the 3.5 million dairy cows in Kenya 0.026 g less P per cow per day would result in savings approximated at Kshs 9 Million annually by feeding MOF concentrates.

Regulation of P balance involves absorption from the small intestine, mobilization from bones, and secretion in saliva. Phosphorus (phosphate) absorption in the small intestine increases on an absolute basis with increasing P intake despite a reduction in apparent digestibility of P in response to increasing dietary P content. The NRC periodically reviews and summarizes the nutrient requirements of various species and issues publications listing these requirements. In the current study, the P requirement is described using a factorial approach (NRC, 2001). The absorbed P requirement to support maintenance, growth, pregnancy, and lactation are calculated and summed, and then adjusted for availability of P in feedstuffs to calculate the amount of P that must be fed.

The livestock industry is facing a number of environmental challenges and there is increased pressure on producers (Calberry, 2004) to manage their nutrients more efficiently. One major area of concern is P and its role as an environmental pollutant. Manure P, spread over land, has the potential to build up in the soil if the rates applied exceed what the crop can remove. With erosion, or if the soil is highly saturated as a result of continuous and excessive application, P may enter surface water causing algae populations to grow rapidly and impair the survival and productivity of other aquatic life.

Intensive animal agriculture (Knowlton et al., 1992; Knolwton, 1998; Lekasi et al., 2001a) has been identified as a significant source of P contamination of surface water; since livestock utilize P inefficiently, excreting 60 to 80% (Knowlton et al., 1992; Chase, 1994a) of the quantity consumed. Therefore, the majority of P brought on to the farm in feed stays on the farm, rather than being exported in meat or milk. As water quality in Kenya gradually gets threatened by contamination with nutrients, primarily N and P, the political response to the threat is accelerating. Consequently, one key change in water quality regulations in the recent years is the global shift from a primary focus on N to an increasing focus on P contamination (Chase, 1994b; Knowlton, 1998) of surface water. However, such a shift is yet to be fully embraced in Kenya.

Increasing public concern in water quality and increased awareness of the effects of concentrated livestock production (NEMA, 1999) has led to the development and implementation of increasingly stringent environmental regulations in Kenya. However, manure quality standards regarding P levels are not explicit. Greater pressure on the industry and corporations from the government (EMCA, 2006) in the recent years to enforce country-wide clean water regulations is yet to significantly increase the level of regulatory pressure on dairy producers.

5.5 Conclusion

The two factors that have the largest effect on milk yield and composition as well as manure P content are dairy concentrate types as influenced by their formulation approaches. Offering MOF supplementary feeds increased milk yield and composition while minimising excess manure-P excretion than LCF concentrates. Nutrition plays a key role and may be the most cost-effective approach to increase productivity as well as reduce P losses from dairy farms. By lowering P content in the diet, P output in manure is also lowered. Environmental regulations in Kenya, which limit the quantity of P applied to land, need to be put in place or be considered for review.

CHAPTER SIX
GENERAL DISCUSSION

6.1 Rationale of the study

Preliminary results from the field baseline survey data analysis on feed industry stakeholders in Nakuru district regarding the relationship of ration formulation objectives indicated a real lack of strong linkages for all dependencies among domain industry players; pointing to a limitation in dairy feed manufacturing decision-making process. In an attempt to offer a sustainable solution to the identified underlying industry constraint, the current study was designed to gather data and make use of existing research as well as NRC 2001, predictive models (chapter 4; Functions 1, 2 and 3) to develop a feeding program which could be used with confidence in formulating MOF rations for lactating dairy cows; especially in the wake of the ever emerging business and production challenges, as well as global environmental regulatory requirements imposed on dairy producers in the 21st century.

The principle objective in formulation of diets for lactating dairy cows is to meet the high nutrient demands of such animals while maximising inclusions of forages in the diet (Mbugua, 1999; McEvoy et al., 2008). Forage intake of lactating cows is an important consideration in maintaining milk fat percentage and in preventing occurrence of digestive and metabolic upsets which may be associated with increased feeding of concentrates. Formulating feed for high-producing cows is sometimes a complex exercise since energy requirements are high and even good quality forages alone cannot meet the energy demands compared to concentrates. Nutrient requirements of lactating cows include considerations for maintenance, growth, gestation and lactation. They are usually fed by one of two major methods of feed distribution. In one method, feed ingredients are fed separately. Forages (mainly maize or Napier grass silage and/or good quality legumes or grass hays or silages) are fed free choice (Mbugua, 1999; Muriuki et al., 2003), and cows will ordinarily consume (2 - 4 %) of their live body weight (Chesworth, 1992; Kennedy et al., 2007; McEvoy et al., 2008; McEvoy et al., 2008), as forage on DM basis. Cows are then individually supplemented with concentrate mixes, the amount and composition of which are dependent upon the cow's level of production while maximising economic returns on IOFC. The second method entails feeding TMR where complete diets are mixed and fed to lactating cows' ad-libitum. However, since the level of production are quite different for the different cows at different stages of lactation, feeding of TMR are most effectively accomplished by dividing cows into distinct production groups at similar stage of lactation and hence nutrient requirements which are fed at specific ration level. The developed MoF-Dairy Edition (2010) program is well adapted to any of these feeding methods.

Target clientele for MoF-Dairy Edition (2010) program include commercial dairy feed millers, dairy farms practicing on-farm concentrate production and TMR feeding, institutions training on dairy nutrition and feeding as well as animal husbandry research centres intending to strengthen food security through increased milk production for sustainable household incomes and livelihoods.

6.2 Methodological approach

6.2.1 Program outline

The proposed MoF-Dairy Edition (2010) program was developed using basic feed formulation principles (standard daily nutrient requirements of cows, ingredient availability and cost, as well as ingredients, nutrients, and inclusion constraints while considering nutrient (P) availability). The MoF-Dairy Edition (2010) attempted to maximise milk profit margins, minimise excess P-inclusion in feeds and hence excretion in manure, while minimising feed cost for improved IOFC. The potential for the MoF-Dairy Edition (2010) program could even be more pronounced if the feed formulation process were undertaken during distinct (wet and dry) seasons of the year since they present marked variations in ingredient availability, cost component and hence quality; with the ingredient CP : P ratio and cost being the key determinant factors. The current study therefore followed a systematic methodology in the development of the MoF-Dairy Edition (2010) program. Firstly, it determined the relationships of feed formulation objectives among feed millers, dairy producers, and feed policy regulators in Kenya; with a view to establishing the existence of (or not) conflicts between business, production and environmental feed formulation goals. Secondly, the development of the MoF-Dairy Edition (2010) program and subsequent functional technical tests and thirdly, subjecting the MoF-Dairy Edition (2010) program to operational validation using experimental lactating Friesian dairy cows under feeding trials. The aim was to generate comprehensive quantitative data on the effectiveness of the MoF-Dairy Edition program from an On-Farm practical perspective. On the whole the three domain industry dimensions namely; manufacturing chain, technical dimension as well as policy regulations were represented.

6.2.2 Program outputs

The program was able to produce tailored feed formulae for a specific cow or cow production groups (including the ingredients utilised, feed composition and the corresponding unit feed cost). Further, the MoF-Dairy Edition (2010) program was able to produce appropriate results at varying business, production and nutrient inclusion constraints as well as generate: tailored reports on the potential unit as well as gross environmental excess P-manure pollution based on existing theoretical literature (published) as well as EMCA, (2006) phosphates regulatory specifications for effluent discharges; business economic analysis of the dairy enterprise production performance under the varying farm situations: detailing the feed quality levels (based on TDN and CP as the most limiting nutrients to milk production in the tropics), concentrate feed supplementation levels per cow per milking and unit as well as overall milk marginal profits following supplementation. Nevertheless, feedstuffs nutrient variability was not addressed comprehensively in the development of the MoF-Dairy Edition program.

6.2.3 Strengths and limitations of the software program

Application of theoretical models to diet formulation for lactating dairy cows enabled the prediction of diet characteristics needed to meet target production levels. Preliminary technical, dynamic and operational system validation results for the MoF-Dairy Edition (2010) program showed that the dairy formulation software product can adapt well to the feed formulation needs of dairy feed manufacturers, nutritionists, ingredient suppliers and sales personnel for the benefit of the livestock feeds industry. It is a client-directed software formulation package which is ideal for all stakeholders in the feed manufacturing industry; suitable for on-farm as well as commercial dairy feed manufacturing. The nutrient requirements of dairy cattle published by the NRC, (2001); in conjunction with results from the field survey, and DMI, MY and P-manure predictive functions, provided the foundation for the program development. The software product is straightforward in balancing feeds to meet daily cow nutrient requirements quickly and accurately with an easy to understand user-friendly interface. Its logical menus and aesthetic screens present clear choices for immediate results. Additionally, the program provides a strong focus in the development; to ensure flexibility of a personal approach in the blend of the art and science of dairy nutrition, feed formulation and individual feeding regimes. Consequently, the user may revise any value or customise NRC daily intake nutrient requirements and recommendations as they may wish, as well as develop feeds tailored to individual customer needs and cow or cow group specifications by entering the cow details and variables such as live body weight and stage of lactation including, daily milk yield and butter fat percentage. Enhanced system flexibility integrates the production of concise, comprehensive feed reports, batch reports and cow feeding formula, as well as potential P-manure pollution and milk yield economic analysis based on IOFC. Options to review reports on the screen, print, copy, or save the data as text files by selecting the 'print to file' are provided.

The fact that feedstuffs used in animal diets have variable composition is well recognised and it is also true that this variability leads to uncertainty in the final diet composition. A crucial aspect to understanding the relevance of variability (Alvarez and Church, 1998; Tozer and Stokes, 2001), in feedstuffs is the question "How does variability in feedstuffs affect the decisions we make in formulating feeds?" The nutritional value of any particular raw material or forage is not the same for all batches used in animal feeds blending. Variability in feedstuffs can arise from two general sources; random variation (often termed 'error') or systematic variation ('bias'). It is essential to minimise random and systematic variations as far as possible. Unfortunately, the software product did not model for the sources of feedstuffs variation that could lead to uncertainty in diet specification, as well as examine the effects of variability in feed resources in diet formulation. Hence the developed MoF-Dairy Edition (2010) program is limited in practically dealing with uncertainty of the nutritional value of feed resources for improved on-farm decision making processes.

6.3 The MoF-Dairy Edition (2010) program: Implications for the feed industry

Currently, about 120 animal feed millers produce various kinds of mainly concentrate feeds of high energy and protein density (Muriuki, et al., 2003; MoLD, 2010a). A number of policy and institutional issues as well as business economic drivers need to be addressed by various stakeholders in the dairy feed industry in charting the way forward (MoLFD, 2006a, 2006b, 2008); if we are to match the ever emerging dairy farming regulatory challenges of the 21st century. Consequently, this calls for elaborate policy formulation and regulatory frameworks as well as feed planning decision-making tools for the day to day running of the fast growing feed industry. Measures to enhance productivity and competitiveness in dairy farming through the supply of affordable and quality animal feeds, adoption of a common feed formulation approach with a view to creating uniformity in feed quality for global markets of dairy products; and institutional frameworks to safeguard (Mbugua, 1999;

Karanja, 2003; Muriuki et al., 2003) and enforce adherence (Tozer and Stokes, 2001), to multiple feed formulation methodology need be considered.

The livestock feeds industry is regulated through the ‘Fertilisers and Animal Foodstuffs Act Chapter 345, 1963’ (revised 1977) and the ‘Standards Act Chapter 496, 1977’ (revised in 1981). Kenya is currently in the process of developing and formulating policies and legislation that deal explicitly with the livestock feeds sector (Muriuki et al., 2003; Technical Team, 2003; Githinji, 2006; Technical Working Group, 2006; Githinji, 2008). As part of the recently instituted countrywide economic reforms, the market for feeds has been liberalised and the feed prices decontrolled. The policy on animal feedstuffs is not yet finalised and a series of stakeholder consultative workshops have been discussing the draft Animal Feeds Bill, 2010. The private sector has always handled the supply and distribution of livestock feeds. The co-operative societies have also been involved in the supply of livestock feed and their involvement is more critical in those rural areas where manufacturers and their distributors may not be attracted (Muriuki et al., 2003; Githinji, 2006; Githinji, 2008). These industry actors present a potentially huge consumer market for dairy feed software formulation packages such as the MoF-Dairy Edition (2010) program, which is likely to provide a tailor-made tool in feed manufacturing decision-making process.

The KEBS is responsible for setting the quality standards for all products sold in or imported into the livestock feed market in Kenya. To enforce standards for animal feeds, KEBS officials are mandated to conduct random audit visits, and draw and take samples for analyses. However, this process alone may not always guarantee sustainable feed quality since no attempts are ever made to audit the actual feed manufacturing decision-making process as well as the ration formulation methods followed to compound concentrate feeds sold out to the dairy producers in Kenya. It is, perhaps, time feed quality policy regulation went beyond just checking the feed samples but also embrace feed formulation methodology as one way of strengthening animal feed quality control practices; in readiness for the ever emerging challenges to the modern dairy producer.

The government of Kenya administers policy and publishes regulations for livestock and livestock waste management-related issues through the MoALF and NEMA respectively. The NEMA farm waste management policy covers programs on improved livestock production under sustainable environmental management. However, efforts on how to deal with manure as a waste and (or) fertility product are weak. Therefore, additional environmental regulations specific to excess manure pollutant nutrients may include the incorporation of MoF Dairy Edition (2010) program as a regulatory tool; since it can be used under different situations to assist livestock managers to plan diets and/or feed millers to adhere to excess pollutant nutrients policy regulatory requirements.

6.3.1 The dairy feed manufacturing environment

Feed millers are registered as companies by the Registrar of Companies through the Companies Act Cap (486) and licensed by the respective Local Authorities. All together, about 120 millers have been registered and licensed to operate in Kenya (MoLD, 2009). The government has only recently developed a policy for the feed sector and a proposed Animal Feeds Bill, 2010 is currently undergoing stakeholder consultation (Muriuki, et al., 2003; Githinji, 2006; Technical Team, 2006; Technical Working Group, 2006; Githinji, 2008). Policies that directly affect cattle feeds such as decontrolled prices and liberalised marketing were implemented as part of the economy-wide Structural Adjustment Programmes. Unfortunately, attempts to control feed quality from the manufacturing process; that involves people, formulation methods, products and policy regulatory guidelines has not been addressed in the current Animal Feeds Policy and Regulatory Framework. One way to entrench feed quality into the proposed Animal Feeds Draft Bill 2010 would be to champion the need to adopt a common feed formulation methodology and use of uniform software programs that optimise business, production as well as policy regulatory goals collectively; such as the MoF-Dairy Edition (2010).

In 1996, the MoALD responded to producer's quality concern of various farm inputs by appointing a team to act as inspectors for various farm inputs such as fertiliser and animal feeds. The team whose task was to ensure that inputs met the prescribed minimum quality standards included all DLPOs and other senior ministry officials. To date, the team has not been activated and some of the members have since left government service (Muriuki et al., 2003; Githinji, 2006; Githinji, 2008). Thus leaving the quality assurance function to be performed on behalf of the government by KEBS, which is constrained, in the opinion of many stakeholders including producers and feed manufacturers, by lack of capacity or will to regulate the feed sector. Veterinarians are gazetted feed inspectors, but are rarely active in this capacity. Weak policy and lack of a specific regulator, as well as lack of capacity to regulate (Muriuki et al., 2003; Muriuki, 2006; Technical Working Group, 2006), is believed to have created an environment that makes it possible for some manufacturers to occasionally supply substandard feeds. To arrest the current state of industry weak coordination, potential feed quality inspectors may be trained on MoF manufacturing principles as part of the sub-sector effort to strengthen the ministry feed inspectorate unit. Consequently, a regulatory framework that encompasses auditing of feed formulation approach and feeds sampling is likely to replace the long list of potential inspectors and enhance quality control checks earlier than damages are done; as well as save on industry unnecessary operational costs.

6.3.2 Minimum P-excretion for environmental management

As Kenya engages top gears in readiness for the Vision 2030 industrialisation goal (Kenya Vision 2030, 2008), attention is fast shifting to the quality of service offered by state agencies charged with regulating investments; such as NEMA and KEBS, which have come into sharp focus against the backdrop of the rising tide of entrepreneurial culture (Omondi, 2008). A primary regulatory issue associated with livestock production is manure storage and disposal. Currently, the livestock industry is facing a number of environmental challenges and there is increased pressure on dairy producers to manage their excess manure nutrients more efficiently. One major area of concern is P and its role as a potential environmental pollutant (Dave, 2004; Jodi, 2004; Ayako, 2005).

Nutrient management has become increasingly important since NEMA waste management regulations were implemented in Kenya (EMCA, 2006). Consequently, livestock producers, feed suppliers, and extension educators are challenged with on-going developments in waste management regulations. The government of Kenya administers policy and publishes regulations for livestock and livestock waste management; and related issues through the MoALF and NEMA respectively. The NEMA established under the Environmental Management and Coordination Act (EMCA) No. 8 of 1999, is the principal instrument of government in the implementation of all policies relating to environmental management. The NEMA farm waste management policy covers programs on improved livestock production under sustainable environmental management (NEMA, 1999; EMCA, 2006; MoLD, 2009). Currently, the NEMA waste and nutrient management planning is focused on crop nutrient management and waste treatment. However, efforts on how to deal with manure as a waste and (or) fertility product are weak (EMCA, 2006; Lekasi et al., 2001a; Lekasi et al., 2001b; Ayako, 2005). Therefore, additional environmental regulations specific to excess manure pollutant nutrients will continue to be developed and implemented in Kenya; since NEMA regulations on dairy farm manure storage and disposal, animal health and safety have implications for how livestock, milk and other dairy products are produced and marketed.

Diet plays a very important part in the overall farm balance of P. Excretion of P-manure is directly related to P consumption by the cow. Research has shown that reducing dietary P concentration (Tozer and Stokes, 2001; Qinghua Liu, 2003; Dave, 2004; Jodi, 2004; Jenni, 2006; Arriaga et al., 2009) can have a tremendous impact on the overall P management on farms. The fourth schedule of EMCA, (2006); Regulation 22, Y37 sections a, b, and c only stipulates the acceptable levels of organic phosphates wastes considered hazardous; and none for inorganic phosphates which are considered critical environmental aquatic pollutants from manure. Whilst the livestock waste regulations are promulgated and enforced by NEMA, it is not yet clear which regulations specifically address concentrate feeding operations in Kenya; since cow manure (faeces and urine) entering waterways does not go through municipal treatment system processes. Thus presenting challenges to MoF-Dairy Edition (2010) package in its attempt to determine the potential P-manure environmental pollution. Consequently, the formulation program's potential manure P-balance reports were based on both published literature (5 g/kg DM manure) as well as EMCA, 2006 (30 mg /Litre Waste Effluent) guidelines on waste management for phosphates, presenting a dilemma. Hence, manure nutrient management guidelines in Kenya are not yet comprehensive and as such will continue to be developed further with a view to explicitly addressing the ever emerging industry regulatory issues.

6.3.3 Business economic analysis

The multiple objectives feed formulation approach can be used in different situations to assist livestock managers to plan diets and/or feeding strategies that may allow them to best meet their dairy economic and business objectives as well as policy requirements (Tozer and Stokes, 2001; Thorne and Dijkman 2001). Dairy ration formulation aims at minimizing costs while maintaining a specified milk production level. The production function for milk yield can be represented thus:

$$Y = f(L, F, \theta),$$

where Y is the milk yield, L is labor input, F is feed input, and θ is defined as random states of nature that affect milk production, such as weather conditions and stress levels on cows. The dairy producer evaluates different methods to reduce the cost of production depending on input levels. In particular, they evaluate the nutrient composition of different feeds to determine if a less expensive feedstuff can be substituted in the ration to decrease input costs while maintaining nutritional requirements for a specified milk production level. Standard dairy cattle nutritional requirements and specific cow production performance were considered in the MOF-Dairy Edition program development. The formulation contained all known feeding and nutritional inputs and animal production outputs. The methodology utilized feedstuffs based on cost and composition, animal performance (kilograms of milk) as a function of nutrients and total animal product output (Varela-Alverez and Church, 1998; Tozer and Stokes, 2001). Produced milk gave the calculated revenues while the cost of feed was an expense. The objective was to maximize on milk profits; within the confines of sustainable dairy production. The formulation used predicted MY and DMI of the cow, production response to nutrients intake, and daily nutrients requirements for lactating cows based on NRC, 2001 specifications.

Smallholder dairy production contributes about 56% and 70% of total and marketed milk production respectively (Omore et al., 1999). The productivity per animal from these farms remains low; partly due to quality variation (MoLD, 2009), of available commercial concentrate supplementary feeds. From the public interest point of view, the role of animal feed manufacturers is mainly to make feeds available to dairy producers at affordable prices, at the right time and most importantly, to ensure consistent quality in conformity with set standards (Muriuki et al., 2003; MoLD, 2007, 2009). They are expected to be efficient in their manufacturing, keeping pace with new technologies and global feed standards as well as emerging regulatory guidelines and be able to translate their efficiency into competitive prices, and also promote proper use of concentrate feeds within the dairy industry. Therefore, adoption of a feed formulation program; such as MoF-Dairy Edition, that attempts to offer economic predictions per unit input into dairy farming is probably one of the best tools that can potentially transform the feed industry.

While milk production is important, it is the average cost of milk production which is the key driver of marginal milk profits (Omore, et al., 1999; Staal, et al., 2003; Thorne and Dijkman 2005; Mathew, 2009). Additionally, the choice of breed and management aspects is synergetic to supplementary feeding and hence the relevance of the MoF-Dairy Edition to modern dairy feed manufacturing process. In effect, supplements should be used to manage pasture, not to feed the animal. Supplementary feeding is only beneficial when there are insufficient pastures. There is no point in wasting pasture or compromising quality due to feeding supplements. The quality of harvested and consumed pastures explains the majority of the variations in milk revenues between farms (Mathew, 2009; Tarrant et al., 2010). To guarantee sustainable dairy profitability, supplements should therefore be used only to fill a true concentrate feed nutritional deficit so that generated liquidity and cash flow can ensure business development and provide opportunities for future growth and expansion.

6.4. Conclusion and recommendations

The current feed manufacturing process is unidirectional in favour of feed millers and as such is limited in optimising business, production, as well as policy regulatory goals collectively. Sustained feed manufacturing for improved livestock productivity will depend upon finding solutions to these limitations. Such solutions will include innovations towards broad-based and all-inclusive feed manufacturing decision-making processes that appropriately capture and rigorously integrate the needs of all industry actors. Additionally, the current rate of development in desktop computing facilities and availability of programming tools for rapid development of user-friendly interfaces; in conjunction with MY, DMI, and P-manure functions can be implemented with success in delivering tailored-software products suitable for providing decision support tools in dairy feed manufacturing. A common multiple objectives feed formulation methodology needs to be entrenched into the proposed Kenya Animal Feedstuffs Draft Bill (2010) for effective policy formulation and regulatory frameworks that are responsive to a wide range of circumstances. Emerging global economic, production as well as environmental regulations are now driving the need for broader policy, institutional as well as regulatory frameworks that include auditing of both feed formulation methodology and manufacturing process approach; in addition to the traditional concentrate feeds sampling. The outcome of the feeding trial supports previous studies recommending the need to adopt energy-protein balance in diets under concentrated dairy feeding operations. However the study goes further and suggests that the MOF approach to dairy feed formulation offers the potential to balance energy-protein as well as protein-phosphorous for sustainable business, production and environmental management gains.

Predictive functions for MY, DMI and P-manure derived from the NRC 2001, and research observations were incorporated in the development of the multiple objectives dairy feed formulation program. The developed MoF-Dairy Edition software product was able to calculate daily nutrient requirements of a lactating cow or cow groups at varying LBW, WIM, MY, and BF content and consequently, dynamically formulate a balanced dairy diet under the prevailing constraints for that instance. Results from the current study provided essential information about the potential to incorporate multiple objectives as critical formulation goals in dairy cattle feeding. Specifically, the model considered ingredients costs, milk yields and marginal profits and phosphorous excretion as critical multiple feed formulation goals; under varying business, production and policy regulatory conditions. The current study has further demonstrated that the MoF-Dairy Edition (2010) software package can be a useful tool for the planning, procurement and blending of concentrate feeds and can therefore provide a more realistic platform to inform decision-making in the dairy cow feed manufacturing chain. However, the current study did not include ingredients nutrient composition variability in dairy cow diet formulation as a critical goal. Further work on the examination of the effects of variability in feed resources in diet formulation and its influence in providing a practical solution to the uncertainty in the nutritional values of feed ingredients for improved dairy nutrition and feeding is needed. However, the MOF approach potentially offered a solution to maximise milk yields and profits and reduce the excretion of excess P in manure.

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APPENDICES

1. **Field survey instruments for feed millers, dairy producers, KEBS, and NEMA**

Questionnaire Number: ___________
Respondent Name: _______________ Respondent Category: ______________________
The following structured questionnaire is geared towards a deeper understanding of existing association between actors in animal feed manufacturing industry in Kenya with a view to enhancing industry-research-training linkages.

Kindly indicate your rate of agreement with the following statements on a 5-point Likert scale described as:

Strongly agree = 5, Agree = 4, Undecided = 3, Disagree = 2, and Strongly disagree = 1:

for every positive statements and vice versa for negative and neutral statements by filling in the appropriate box numbers: **1, 2, 3, 4, or 5** accordingly.

A. Least cost of ingredients

1. I am familiar with dairy feed formulations by manufacturers ☐

2. Current feed manufacturing optimises least cost of ingredients as a priority. ☐

3. Ingredient cost is considered a critical ration manufacturing goal in dairy ☐ feed

4. Current dairy manufacturing approach is the best for dairy feed supplements. ☐

5. Purchase of ingredients is based on cost and quality considerations. ☐

6. Available commercial dairy feeds are affordable. ☐

7. Ingredients cost is a challenge in commercial feed manufacturing. ☐

8. Ingredients availability is a challenge in commercial feed manufacturing. ☐

9. Available commercial dairy feeds address dairy producer needs. ☐

B. Maximum milk profit margins

10. Profit from milk sales is a priority in dairy manufacturing.

11. Complain about high feed prices are send to feed millers.

12. Complain about low milk production from dairy feeds are send to feed millers.

13. Commercial dairy feeds are balanced for maximum milk production.

14. High feed prices correspond to high balanced feeds.

15. Use of commercial dairy feeds guarantees profitability in milk

16. Available commercial dairy feeds address feed quality specifications.

17. Available commercial dairy feeds address production specifications

18. Available commercial dairy feeds address environmental specifications

C. Minimum P-excretion

i. Feed quality issues

19. I am aware of feed quality specifications in feed manufacturing.

20. I advise on feed quality standards.

21. Market dairy meal adheres to feed quality regulatory specifications.

22. Market dairy meal contains **minimum** allowable limits of crude protein.

23. Market dairy meal contains **minimum** allowable limits of Phosphorous (P).

ii. Environmental health issues

24. I regard cow manure disposal an important environmental protection concern.

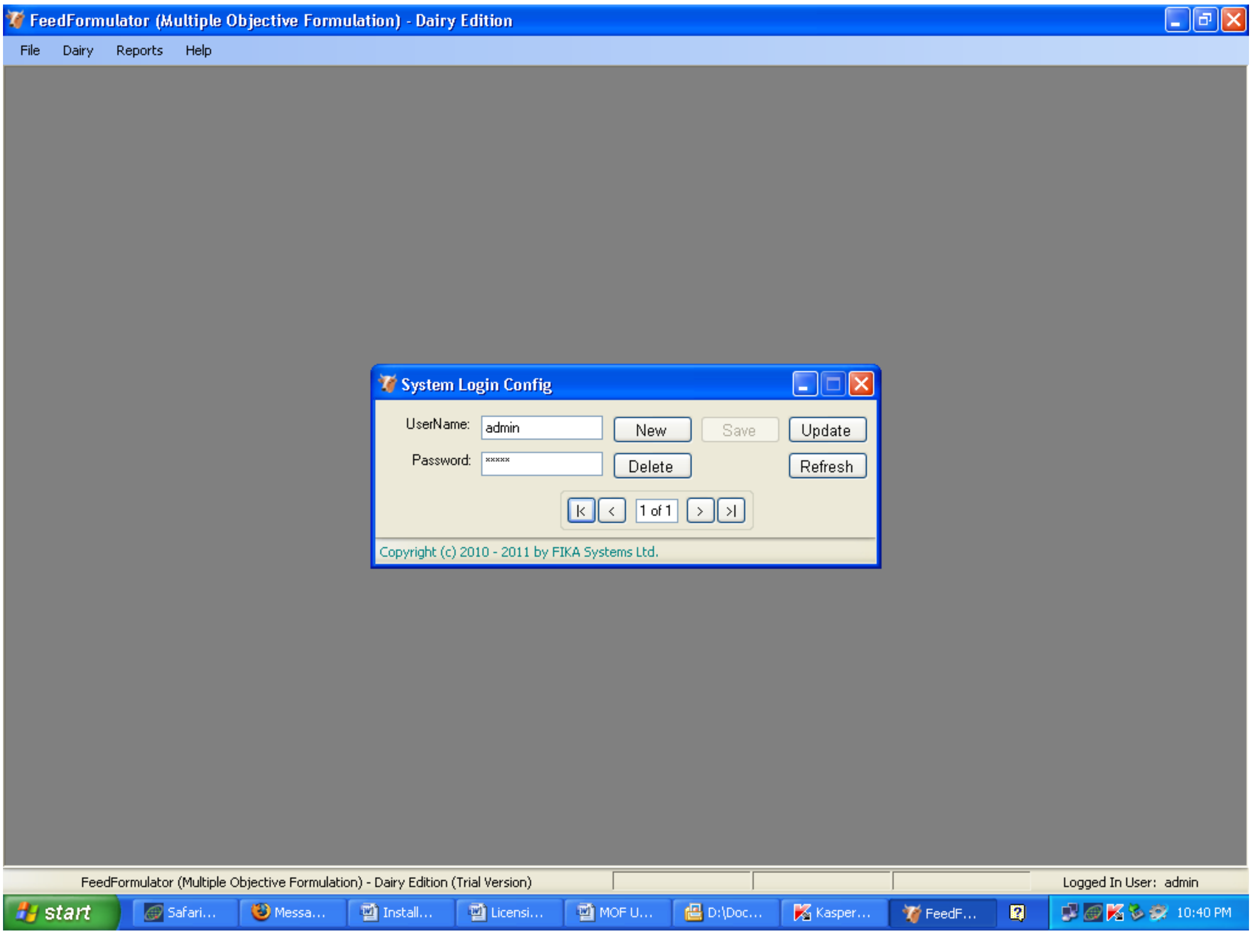
25. I am aware of regulations on cow manure management specifications to environment.

26. I am aware of proper environmental issues for healthy water quality.

27. I am aware of environmental implications of cow manure pollution on water quality.

2. Technical validation for the MoF Dairy Edition (2010) Program

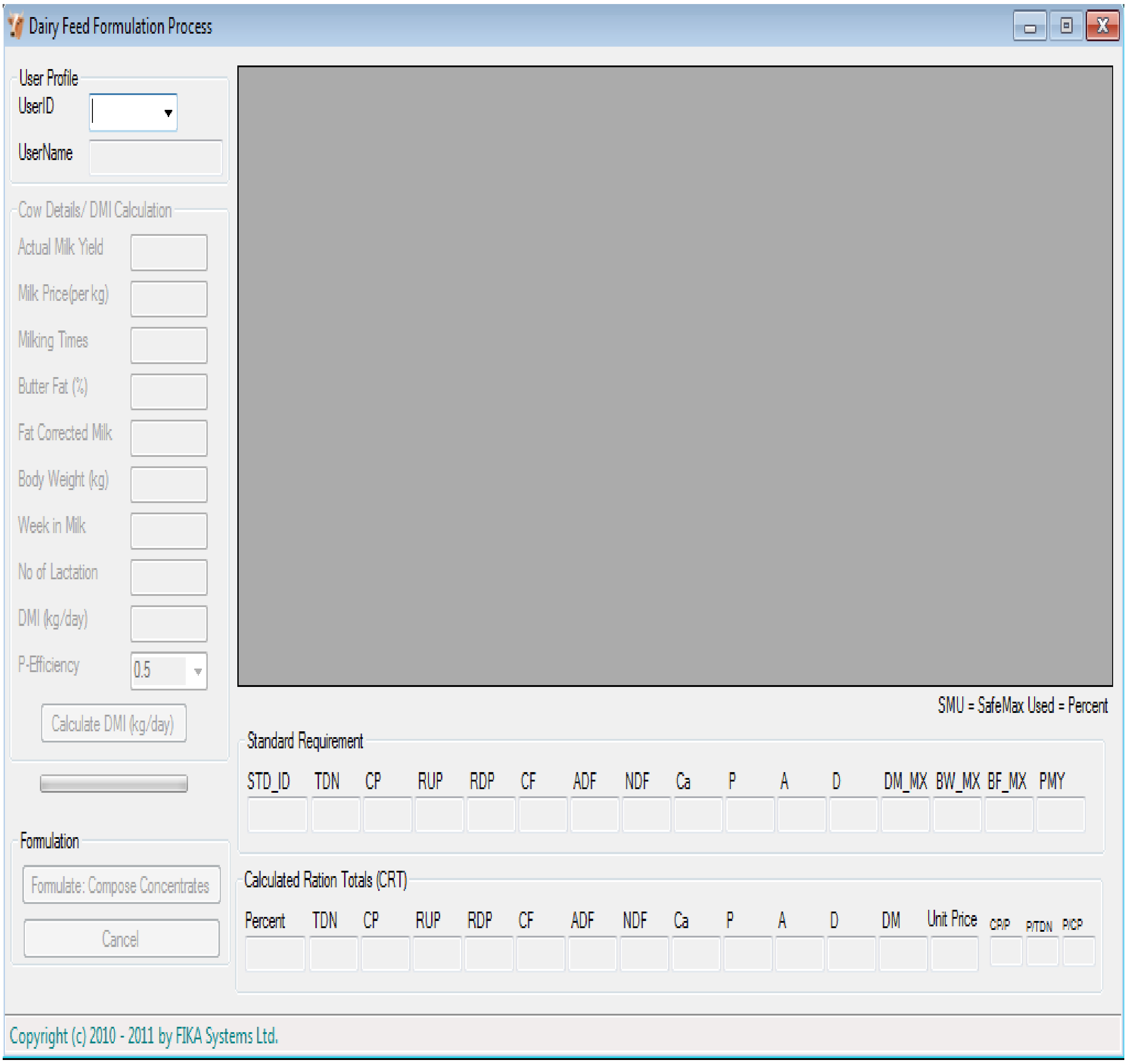
a. Log-in configuration with system security



b. Daily nutrient requirements for dairy cow database (NRC 2001)

STD_ID	DM_MIN	DM_MAX	BW_MIN	BW_MAX	BF_MIN	BF_MAX	TDN	CP	RUP	RDP	CF	ADF	NDF	Ca	P	A	D	PMY	NoL_GT3
1	8	18	400	499	5.00	6.00	63.00	12.00	4.40	7.80	17.00	21.00	28.00	0.43	0.28	3200.00	1000.00	7.00	☐
2	8	18	400	499	4.50	4.90	63.00	12.00	4.40	7.80	17.00	21.00	28.00	0.43	0.28	3200.00	1000.00	8.00	☐
3	8	18	400	499	4.00	4.40	63.00	12.00	4.40	7.80	17.00	21.00	28.00	0.43	0.28	3200.00	1000.00	10.00	☐
4	8	18	400	499	3.50	3.90	63.00	12.00	4.40	7.80	17.00	21.00	28.00	0.43	0.28	3200.00	1000.00	12.00	☐
5	8	18	400	499	3.50	3.90	63.00	12.00	4.40	7.80	17.00	21.00	28.00	0.43	0.28	3200.00	1000.00	13.00	☑
6	10	19	500	599	5.00	6.00	67.00	15.00	5.20	8.70	17.00	21.00	28.00	0.51	0.33	3200.00	1000.00	13.00	☐
7	10	19	500	599	4.50	4.90	67.00	15.00	5.20	8.70	17.00	21.00	28.00	0.51	0.33	3200.00	1000.00	17.00	☐
8	10	19	500	599	4.00	4.40	67.00	15.00	5.20	8.70	17.00	21.00	28.00	0.51	0.33	3200.00	1000.00	20.00	☐
9	10	19	500	599	3.50	3.90	67.00	15.00	5.20	8.70	17.00	21.00	28.00	0.51	0.33	3200.00	1000.00	24.00	☐
10	10	19	500	599	3.50	3.90	67.00	15.00	5.20	8.70	17.00	21.00	28.00	0.51	0.33	3200.00	1000.00	27.00	☑
11	12	20	600	699	5.00	6.00	71.00	16.00	5.70	9.60	17.00	21.00	28.00	0.58	0.37	3200.00	1000.00	20.00	☐
12	12	20	600	699	4.50	4.90	71.00	16.00	5.70	9.60	17.00	21.00	28.00	0.58	0.37	3200.00	1000.00	25.00	☐
13	12	20	600	699	4.00	4.40	71.00	16.00	5.70	9.60	17.00	21.00	28.00	0.58	0.37	3200.00	1000.00	30.00	☐
14	12	20	600	699	3.50	3.90	71.00	16.00	5.70	9.60	17.00	21.00	28.00	0.58	0.37	3200.00	1000.00	36.00	☐
15	12	20	600	699	3.50	3.90	71.00	16.00	5.70	9.60	17.00	21.00	28.00	0.58	0.37	3200.00	1000.00	40.00	☑
16	14	20	700	799	5.00	6.00	75.00	17.00	5.90	10.30	15.00	19.00	25.00	0.64	0.41	3200.00	1000.00	26.00	☐
17	14	20	700	799	4.50	4.90	75.00	17.00	5.90	10.30	15.00	19.00	25.00	0.64	0.41	3200.00	1000.00	33.00	☐
18	14	20	700	799	4.00	4.40	75.00	17.00	5.90	10.30	15.00	19.00	25.00	0.64	0.41	3200.00	1000.00	40.00	☐
19	14	20	700	799	3.50	3.90	75.00	17.00	5.90	10.30	15.00	19.00	25.00	0.64	0.41	3200.00	1000.00	48.00	☐
20	14	20	700	799	3.50	3.90	75.00	17.00	5.90	10.30	15.00	19.00	25.00	0.64	0.41	3200.00	1000.00	53.00	☑
																			☐

c. Formulation process



3. Operational validation data for the MoF Dairy Edition (2010) Program

a. Table i: Production parameters of Lactating Dairy Cows at Ngongongeri Farm Njoro used in the feeding trial for Period I and II

	Serial Number	Cow Name (Number)	Live Body Weight	Weeks in Milk (WIM)	Milk Yield (MY)	Butter Fat %	Milk Protein %
Group A P1: (MoF) P2: (LCF)	2	BETTY 435	421	6	14	3.61	3.09
	4	FARASI 383	382	8	14	3.35	3.15
	6	NYANYA 537	389	9	14	3.68	3.12
	9	UGUNJA 583	361	15	11	3.68	3.12
	10	THIONGO 476	419	18	9	3.33	3.09
	11	KULA 24	393	12	8	3.99	3.17
Average			394	9	12	3.61	3.12
Group B P1: (LCF) P2: (MoF)	1	MABATI 514	409	6	12	3.80	2.98
	3	KARAYA 518	433	8	16	3.96	3.20
	5	CHUMO 414	444	9	13	3.51	3.08
	7	MACHO 519	354	16	8	4.43	3.31
	8	NAMELESS 485	489	14	10	4.37	3.12
	12	TINTIN 452	487	10	14	3.38	3.18
Average			436	11	12	3.91	3.15

b. Table ii: Chemical composition of concentrate ingredients at Naku Modern Feed Mill- Nakuru during period I and II (June to August 2011)

	Analysis (% of DM)							
Ingredients	DM %	TDN	CP	CF	NDF	Ca	P	Unit price/kg Kshs
Fish meal	89.50	67.55	48.73	11.27	3.00	0.17	0.75	58.00
Cotton meal	95.86	58.63	29.29	9.47	34.50	0.26	0.62	51.00
Sunflower meal	90.09	57.66	26.88	12.63	33.07	1.73	0.57	39.00
Maize germ	88.62	90.68	10.53	10.30	5.52	0.02	0.53	23.00
Wheat bran	91.80	60.76	15.15	5.22	12.17	0.09	0.92	17.50
Wheat pollard	88.75	75.82	13.96	3.80	5.87	0.18	0.55	23.50
Dairy premix	98	0	0	0	0	0.65	0.03	250.00
Limestone	100	0	0	0	0	15.87	0.08	60.00
DCP	97	0	0	0	0	13.43	5.08	80.00
Magadi soda	21	0	0	0	0	4.13	0.17	140.00
Molasses	75	71	2.3	0	0	0.42	1.36	350.00

c. Table iii: Inclusion rates (%) of ingredients used in composing LCF and MOF concentrates at NakuModern Feed Mill-Nakuru during period I and II (June to August 2011)

	Concentrate type and inclusion rate (%)			
Ingredients	LCF	MOF	SafeMin	SafeMax
Maize germ	13.96	20	0	100
Wheat bran	4.41	15	0	100
Wheat pollard	30.07	20	0	100
Molasses	10.07	8	0	15
Sunflower cake	25.07	20	0	25
Cotton cake	13.6	14.5	0	35
Fish meal	0.57	0.5	0.5	3
Dairy premix	0.57	0.5	0.5	2
Limestone	0.57	0.5	0.5	3
DCP	0.57	0.5	0.5	2
Magadi soda	0.57	0.5	0.5	2

d. Table iv: Phosphorous bio-availability of common dairy feedstuffs

Ingredients	Bio-availability range %	Working average %
Maize germ	45-69	50
Wheat bran	45-69	50
Wheat pollard	45-69	50
Molasses	70	70
Sunflower cake	50-70	60
Cotton cake	50-70	60
Fish meal	90-95	90
Dairy premix	90-95	90
Limestone	95-98	96
DCP	93-95	94
Magadi soda	25-35	30

Source: Adapted from Micro-minerals, 1975

4. List of publications in refereed international scientific journals and book chapter

a. Mutua S M, A Y Guliye, B O Bebe, and A K Kahi (2010), Relationships of feed formulation objectives among feed millers, dairy producers, and feed policy regulators in Nakuru district-Kenya: **(Journal of Livestock Research for Rural Development)**

URL: http://www.lrrd.org/lrrd22/12/mutu22226.htm

b. Mutua S M, A Y Guliye, B O Bebe, A K Kahi and I M Osuga (2011) Economic, production, and environmental effects of commercial dairy feed manufacturing on feed millers, dairy producers, and feed policy regulators in Kenya: implication for decision-making process: **(Book Chapter: on Entrepreneurship: Gender, Geographies and social context in: InTech Open Access Publishers, University Campus, Rijeka, Croatia)**

Book title: Entrepreneurship / Book 1 (ISBN 979-953-307-531-9)

c. Mutua S M, A Y Guliye, B O Bebe, and A K Kahi (2013), Development of MoF-Dairy Edition (2010) Program-Kenya: A software that brings new approach to Dairy nutrition and feeding: **Journal of Agricultural Science, 2013:**

URL: http://dx.doi.org/10.5539/jas.v5n11p208

d. Mutua S M, A Y Guliye, B O Bebe, and A K Kahi (2014), Comparison of least-cost and multi-objective dairy feed formulation programs: feeding trial validation results (**Journal of Tanzania Society of Animal Production-2013)**

5. **Conference presentations/proceedings**

a. Animal Production Society of Kenya (APSK-Kenya) at Kitale-Club, Kitale from 19th through 21st April 2011

   Paper title: Linkages among actors in the Livestock feeds industry

b. National Council for Science and Technology(NCST) Innovation category at KICC-Nairobi from 16th through 21st May 2011

   Paper title: Innovations in Animal Agriculture: applied ICT

c. East Africa Agricultural Productivity Project (EAAPP)/KARI Project on On-Farm Dairy Formulation Sensitisation Workshop for Feed Industry Stakeholders-April 2011

   Paper title: **Feed formulation goals for industry domain actors**

d. Nairobi Agricultural Trade Fair-2011: Ministry of Livestock development innovation for Feeds Section: **On-Farm Utilisation of local feed resources for profitable Livestock farming; using applied ICT in Dairy Feed Formulation Technologies-September/October 2011**

e. Feed industry stakeholder forum at KLBO-Nakuru, Kenya: **Design, development and functioning of MoF-Dairy Edition (2010) program: Implications for the dairy feed industry-) October 2011**

f. Animal Production Society of Kenya (APSK-Kenya) at Nyeri-Green Hotel, Nyeri from 11th through 13th April 2012

   Paper title:

   Development of MoF-Dairy Edition (2010) Program: A Software that Brings a New Approach to Dairy Nutrition and Feeding

g. Tanzania Society of Animal Production (TSAP-Tanzania) at Arusha-Olosit Hotel, Arusha from 21st through 25th October 2013

   Paper title:

   Comparison of least-cost and multi-objective dairy feed formulation programs: feeding trial validation results

6. Further research work

a. Examine the fundamental principles in the development of multiple objective feed formulation (MoF) Dairy Edition-2010 program
b. Perform a cost-benefit or sensitivity analysis MoF-Dairy Edition (2010) under On-Station as well as On-Field/Farm conditions
c. Conduct digestibility trials for MoF-Dairy Edition (2010) under varying economic, production and policy conditions
d. Incorporate county feed variation sources (soil, climate, nutritional levels and forage cultivars) in the development of Livestock feed formulation programs
e. Re-Engineer MoF-Dairy Edition (2010) program and integrate feedstuffs nutrient variability modules