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Full Length Research Paper

A simple method of formulating least-cost diets for smallholder dairy production in sub-Saharan Africa

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Smallholder dairy farmers in sub-Saharan Africa are constrained by inadequate supply of good quality protein sources particularly during the dry season. Commercial protein concentrates are expensive and not readily accessible. Multipurpose forage legumes and other non-conventional protein sources available on-farm have been promoted as alternative cheaper protein sources. The major problem faced by smallholder dairy farmers however is the formulation of diets balanced for the key nutrients and also being cost-efficient. This paper presents a step by step spreadsheet based procedure of diet formulation for smallholder dairy production. The procedure ensures that the diet is balanced for all the key nutrients, is low-cost and the user has significant control over the formulation process. An example using this formulation method incorporating the fodder legumes *Leucaena diversifolia, Leucaena pallida, Leucaena esculenta, Acacia angustissima* and *Calliandra calothyrsus* indicate a cost reduction from 10% on *C. calothyrsus* to 30% on *L. diversifolia* inclusion when compared to the conventional dairy meal concentrate (US$ 0.34/kg). This ration formulation method is recommended for use by livestock extension advisors and smallholder dairy farmers to quickly formulate low-cost diets using locally available feed sources so as to optimise the feeding of dairy animals at the farm level.

Key words: Feed formulation, fodder trees, non-conventional protein sources, sustainable farming.

INTRODUCTION

In dairy production, the feeding programme affects profitability more than any other single factor. The costs of feeding make up 60 - 80% of the variable costs of milk production (Webster, 1993). Without good feeding programmes, the benefits of good breeding and management programmes cannot be realised. Practical feeding of dairy cows has the following four main themes: (1) assessment of the nutritive value of feedstuffs, (2) description of the nutrient requirements of animals, (3) ration formulation and (4) diagnosis, prognosis and prevention of disorders of nutrition and metabolism (Dunham, 1989).

The nutrients to be supplied in a feeding programme include energy, protein, minerals and vitamins (Pond et al., 1995). These should be supplied in their required amounts to meet specific performance targets. Carbohydrates and fats are the major sources of energy. In Central and southern Africa, the major sources of energy include maize, maize bran, sorghum and barley. Minerals and vitamins are normally incorporated in the diets as pre-mixes. Protein is included in the dairy meal concentrate fraction and has traditionally been provided through protein sources such as cottonseed meal and soybean meal. Due to the high costs and non-availability of these protein sources, readily available supplements are required to optimally feed dairy cows particularly during the dry season (Jera and Ajayi, 2008).

Fodder trees and legumes have been developed and are being widely used by smallholder dairy farmers particularly in East and Southern Africa (Hove et al., 2003. Franzel and Wambugu (2007) estimate that a total of 200 000 smallholder dairy farmers in East Africa are using the fodder legumes for their dairy production. A significant number of smallholder farmers in Malawi and Zimbabwe are also using these fodder legumes

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Abbreviations: CP, crude protein; **ME**, metabolisable energy.

(Chakeredza et al., 2007).

The major significant fodder trees grown by smallholder farmers include *Calliandra calothyrsus, Leucaena diversifolia, L. pallida, L. esculenta* and *Acacia angustissima* (Hove et al., 1999). Smallholder dairy farmers in eastern and southern Africa have been planting these fodder legumes either as scattered trees in the crop lands, as hedges around the farm compound, along terrace edges on sloping land, along permanent contour bunds or intercropped with grasses (Dzowela et al., 1997). The fodder legumes are used in the smallholder dairy animal feeding either through “cut and carry” or included into the dairy meal fraction. The dairy meal normally includes an energy source, protein source, vitamins and minerals. A number of non-conventional feed resources are also being used as protein concentrates for farmers home-mixing. However, there is a problem to formulate diets that are balanced with respect to protein, energy, vitamins and minerals and at the same time being low-cost.

The Pearson square has been widely used in ration formulation process (Wagner and Stanton, 2006). However, its major disadvantage is that one can only balance for one nutrient at a time. It therefore has limited application where farmers have to formulate diets balanced for protein, energy, vitamins and minerals and also being low-cost. Simultaneous equations and matrices should be developed for this purpose and this often requires proficient knowledge in advanced mathematics.

Least-cost formulation is a mathematical solution based on linear programming. This practice is widely used within the commercial feed industry using commercially available software programmes. Least-cost formulation of diets optimises the combination of feed ingredients that supplies the required levels of nutrients at least cost (Rossi, 2004). It requires the professional knowledge of animal nutritionists who take into consideration the nutrient requirements of the target animal and its capability to digest and assimilate nutrients from various available ingredients. Commercial feed formulation software is costly for most extension organisations in developing countries and the return on investment when using them on a small scale does not justify their purchase. These software programmes are also not flexible since the feed database cannot be modified easily and one cannot improve on the programme as and when advances in ration formulation systems take place.

The objective of this paper is to develop a methodology whereby livestock extension advisors to smallholder dairy farmers or farmers themselves can quickly compute rations with a special focus on the inclusion of forage legumes and other non-conventional feed resources into the dairy meal. The assumption is that the forage legume or the non-conventional feed resource will be readily available on-farm as well as being more cost-efficient.

METHODOLOGY FOR DAIRY MEAL CONCENTRATE FORMULATION

In smallholder dairy farming sectors of sub-Saharan Africa, most extension workers have access to a computer at the district office. These computers will be running Windows operating system with Microsoft Office, which includes the spreadsheet programme, Excel®. Elsewhere in the world, spreadsheet programmes have been used in teaching diet formulation to tertiary level students (Pesti and Seila, 1999; Thomson and Nolan, 2001; Ussery, 2007). This is because of the great capability and flexibility of modern spreadsheet programmes. Excel® comes with a programming capability of “SOLVER” function which has linear programming functionality that can be used in least-cost ration formulation.

There is a need to extend the use of the spreadsheet programme to practical field situations for example under smallholder dairy farmer conditions. Extension workers can capitalise on this facility in formulating diets for smallholder dairy farmers. They can easily formulate diets balanced for as many variables as they desire and make the final feed least-cost as well. In this paper we describe how Excel® can be used at the extension worker level for dairy meal feed formulation for smallholder dairy farmers with a special focus on the inclusion of readily available feed resources on the farm. A basic working knowledge of Excel® is all that is required.

Given that smallholder farmers in most cases do not have many feed ingredients to choose from, use of one worksheet will suffice. However, extension workers need to know the chemical composition and costs of the different feedstuffs available to them. In cases where chemical composition of a feed is unknown, values from Topps and Oliver (1993) Handbook for similar feedstuffs can be used as a first approximation. Otherwise laboratory analysis might be necessary.

Step 1: Creating the feed database

The first step is to list the feed ingredients available, their cost and chemical composition as a database. The database can be modified any time and more feed ingredients can be added as and when they become available. An example of how the data can be entered is shown in Figure 1. For simplicity, we will only incorporate three components, namely, crude protein (CP), metabolisable energy (ME) and feed cost. The database can be expanded to incorporate as many nutrients as possible. Table 1 presents an extract of nutrient profiles of common feeds from Topps and Oliver (1993).

Step 2: Diet quality specification

The second step is to lay down the resultant feed quality that needs to be formulated. Data on the nutrient requirements of dairy cattle varying in weights and milk production is given in a simple Excel® spreadsheet (Table 2). Normally, livestock feeds are balanced for protein and energy in addition to the incorporation of vitamin-mineral premixes. For simplicity, let us suppose that the extension worker would want to formulate a dairy meal concentrate of 16% CP and 11 MJ ME/kg. The vitamin mineral pre-mix will be incorporated at 1.4%. This diet approximates to the dairy meal concentrate offered to cows in mid-lactation (Dunham, 1989).

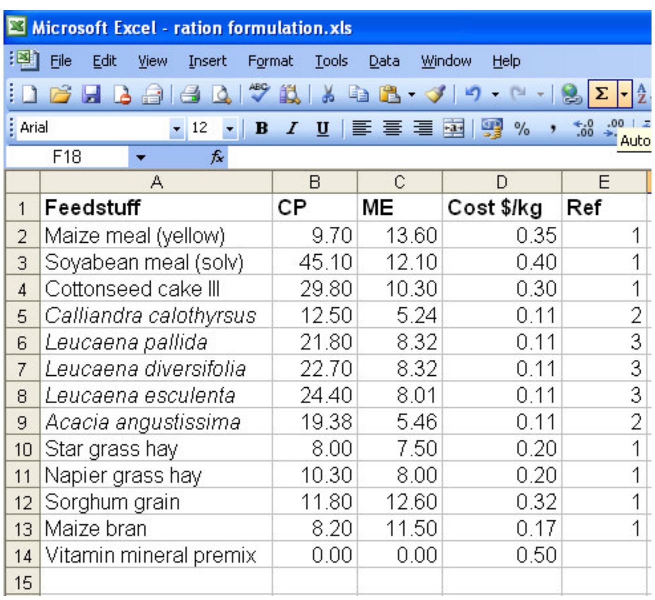
Step 3: Selection of feed ingredients

The next step is for the user to select the feed ingredients to formulate the diet. The first choice will obviously be feeds available on the farm or cheap non-conventional feed resources before the farmer can purchase anything else. These will be listed next to the

Table 1. Nutrient content of common feeds in Central and southern Africa.

Element	DM (%)	ME (MJ/kg)	CP (%)	DP (%)	Ca (%)	P (%)	Vit A IU/g
Forages							
Lucerne (green)	18.2	8.8	25.3	18.8	1.60	0.25	104.0
Napier fodder	14.5	8.0	10.3	6.4	0.36	0.32	-
Giant Rhodes grass	18.7	9.3	13.7	8.1	0.51	0.32	-
Silages							
Maize	40.0	10.5	8.1	4.7	0.27	0.20	-
Sorghum	26.2	8.4	7.8	3.9	0.30	0.22	-
Grains							
Maize grain (white)	90.0	13.9	9.4	5.2	-	0.40	-
Sorghum grain	90.0	12.6	11.8	7.6	0.04	0.33	-
Oilseeds and meals							
Cotton seed meal	94.9	11.0	36.5	29.8	0.20	1.20	0.30
Soybean meal (exp)	92.0	12.2	44.0	34.8	0.25	0.60	0.34
Blood meal	89.6	9.0	93.7	66.5	0.28	0.22	-
Meat and bone meal	96.0	9.7	59.0	47.2	11.20	5.40	-
Mineral Supplements							
Dicalcium phosphate	-	-	-	-	22.0	18.0	-
Monocalcium phosphate	-	-	-	-	16.0	20.0	-
Limestone flour	-	-	-	-	37.0	-	-

DM, Dry matter; ME, metabolisable energy (MJ/kg DM); CP, crude protein; DP, digestible protein; Ca, calcium; P, phosphorus.
Source: Topps and Oliver (1993).



	A	B	C	D	E
1	Feedstuff	CP	ME	Cost $/kg	Ref
2	Maize meal (yellow)	9.70	13.60	0.35	1
3	Soyabean meal (solv)	45.10	12.10	0.40	1
4	Cottonseed cake III	29.80	10.30	0.30	1
5	*Calliandra calothyrsus*	12.50	5.24	0.11	2
6	*Leucaena pallida*	21.80	8.32	0.11	3
7	*Leucaena diversifolia*	22.70	8.32	0.11	3
8	*Leucaena esculenta*	24.40	8.01	0.11	3
9	*Acacia angustissima*	19.38	5.46	0.11	2
10	Star grass hay	8.00	7.50	0.20	1
11	Napier grass hay	10.30	8.00	0.20	1
12	Sorghum grain	11.80	12.60	0.32	1
13	Maize bran	8.20	11.50	0.17	1
14	Vitamin mineral premix	0.00	0.00	0.50	
15					

Figure 1. Feed nutrient database in Excel. 1. Topps and Oliver (1993); 2. Dzowela et al. (1995); 3. Nherera et al. (1998); Costs of forage legume has been adopted from work of Franzel et al. (2007) based on data from Tanga, Tanzania. Other ingredient costs are as prevailing on the Malawi Market as of March 2008.

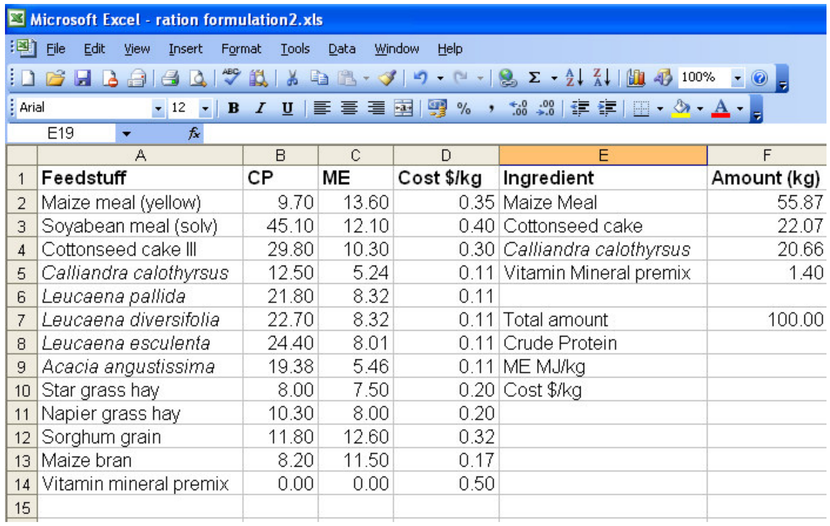
feed database as shown in Figure 2. The initial amounts can be randomly chosen so that the total amount including the vitamin-mineral premix will add up to 100.

Step 4: Working with Excel formulae

The fourth step is to specify the formulae for calculating the crude protein (CP), metabolisable energy (ME) and cost of the formulated feed. To successfully build correct formulae, it is important to have an appreciation of the rules by which formula construction in Excel® proceed. Formulae begin with an equal (=) symbol in the target cell. The results of the formula appear in the worksheet while the formula that calculated the results appears in the formula bar. It is important to use cell references in formulae whenever possible. When one needs to include a cell reference in a formula, it often is easier to point to the cell than it is to type in the cell reference. Using a pointing method will also help avoid typing mistakes. The following steps should be followed in formula construction (Figure 2):

- Select the cell where you want the answer to appear
- Type an = (equal symbol) to begin the formula
- To use a cell reference, click the cell with the mouse or use the arrow keys on your keyboard to select the cell. A marquee (flashing set of dotted lines) appears around the cell you select and the reference appears in the cell where the formula is being built
- Type in the next part of your formula such as an arithmetic operator and continue building the formula
- Press ENTER to complete your formula. The result of the formula displays in the worksheet and the formula appears in the formula bar.

The order of operations for calculations are given by the pneumonic PEMDAS. This refers in order of decrease in priority, to the following: parentheses (), exponents (^), multiplication (*), division (/), addition (+) and subtraction (-). It is important to pay careful attention to this order of arithmetic operations in formula construc-



	A	B	C	D	E	F
1	Feedstuff	CP	ME	Cost $/kg	Ingredient	Amount (kg)
2	Maize meal (yellow)	9.70	13.60	0.35	Maize Meal	55.87
3	Soyabean meal (solv)	45.10	12.10	0.40	Cottonseed cake	22.07
4	Cottonseed cake III	29.80	10.30	0.30	*Calliandra calothyrsus*	20.66
5	*Calliandra calothyrsus*	12.50	5.24	0.11	Vitamin Mineral premix	1.40
6	*Leucaena pallida*	21.80	8.32	0.11		
7	*Leucaena diversifolia*	22.70	8.32	0.11	Total amount	100.00
8	*Leucaena esculenta*	24.40	8.01	0.11	Crude Protein	
9	*Acacia angustissima*	19.38	5.46	0.11	ME MJ/kg	
10	Star grass hay	8.00	7.50	0.20	Cost $/kg	
11	Napier grass hay	10.30	8.00	0.20		
12	Sorghum grain	11.80	12.60	0.32		
13	Maize bran	8.20	11.50	0.17		
14	Vitamin mineral premix	0.00	0.00	0.50		
15						

Figure 2. Feedstuff database and compilation of required mix.

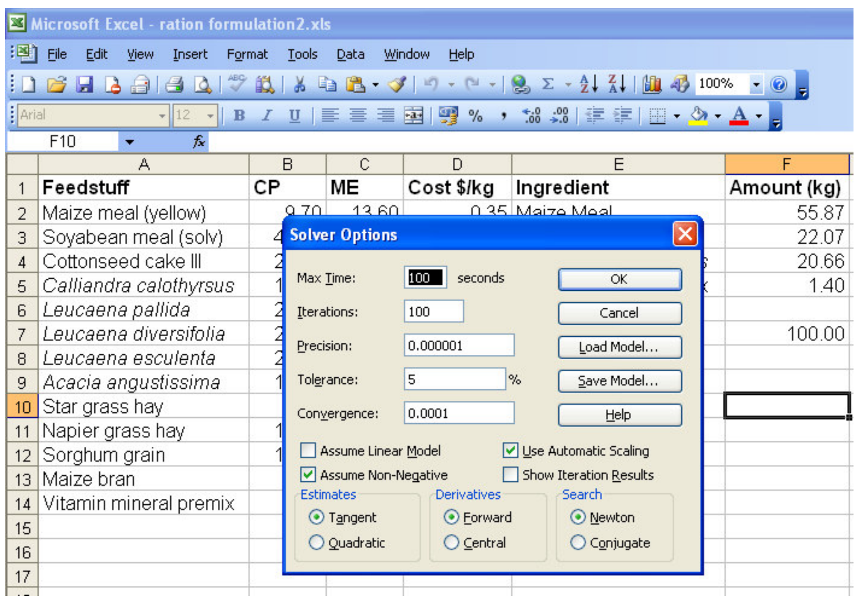


Figure 3. The SOLVER options.

tion, as it is very easy to have erroneous calculations carried out. Infact, having your formulae verified by a second person is best until one becomes comfortable with the process of constructing the formulae.

Four formulae to calculate, respectively, the Total amount, CP, ME and Cost of the resultant ration using the cell references shown in Figure 3 can be built as follows:

1. Total amount = (F2+F3+F4+F5)
2. CP (%) = (B2/100*F2+B4/100*F3+B5/100*F4)/F7*100
3. ME (MJ/kg) = (C2*F2+C4*F3+C5*F4)/F7
4. Cost ($/kg) = (D2*F2+D4*F3+D5*F4+D5*F4+D6*F5)/F7

In each case the user should remember to press ENTER in the formula bar to complete the formula. The fifth and last step is to formulate the diet using the "SOLVER" function.

Step 5: Using SOLVER

It is important for the user to ensure that the SOLVER function is available under TOOLS in Excel® menu bar. If it is not available, the user needs to go through TOOLS and ADD-INS option to activate the SOLVER before proceeding. The original CD from where the Excel® programme was installed may be required. Once the SOLVER is available, the user is ready to formulate the diet. The SOLVER parameters dialog box has an OPTIONS button, which allows access to a submenu where the "use automatic scaling" and "assume non-negative" options should be selected as shown in Figure 3.

By pressing "OK" in the SOLVER options dialog box returns the user to the previous menu (Figure 4) which allows for the completion of the formulation exercise. The cost/kg (cell F10) is selected as the target cell and is set to seek minimum value, while

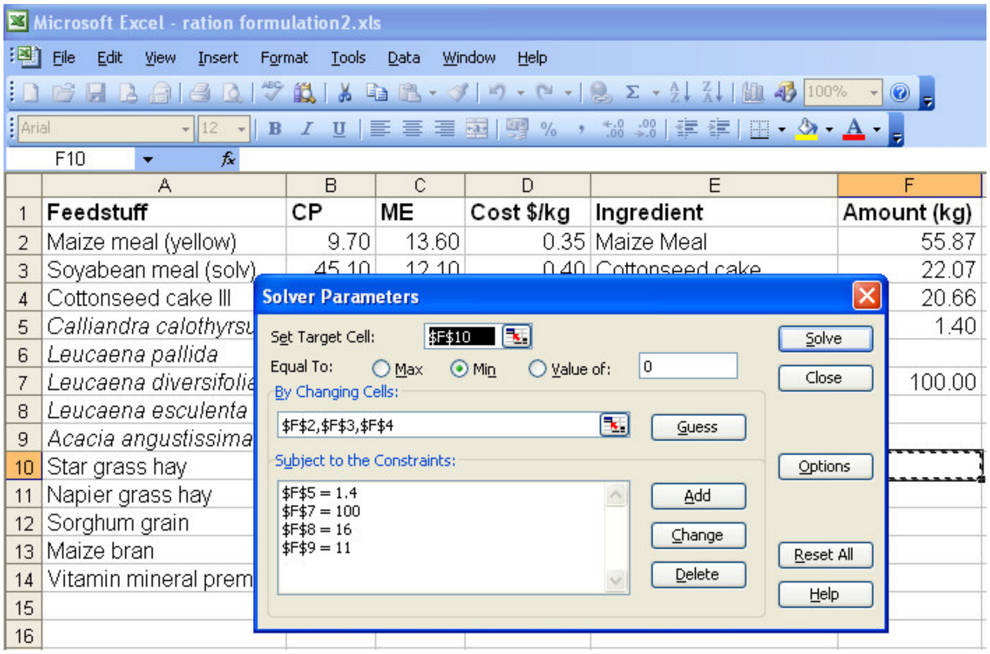


Figure 4. SOLVER PARAMETERS dialog box.

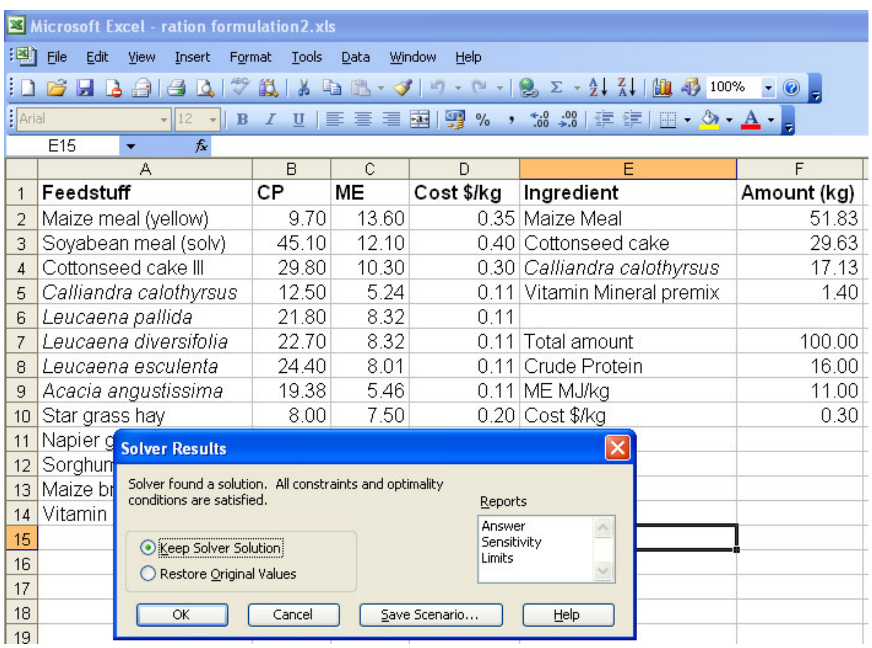


Figure 5. Least-cost diet formulation.

the cells F2, F3 and F4 are selected as “cells to change”. Cells F2, F3 and F4 in the “cells to change” dialog box are separated by commas.

Finally the constraints are set in the subject to the CONSTRAINTS window, setting the constraints for ME, CP, Total amount and vitamin-mineral premix to desired levels. In our example, ME will be set to 11, CP will be set to 16 and vitamin-mineral premix will be set to 1.4 (Figure 4).

On choosing the SOLVE button in the SOLVER PARAMETERS dialog box, the optimum diet will be produced and the options to save the new values and to view ancillary sensitivity reports will appear (Figure 5). These reports, if invoked, give useful information such as price changes necessary for unused ingredients to be included and other aspects of the formulation. Taking the case for inclusion of *Calliandra calothyrsus* for example, Figure 5 shows that *C. calothyrsus* can be included at 17.13 % of the total dairy meal concentrate fraction and maintain the overall 16 % CP content and 11 MJ ME/kg dry matter energy content. The process is carried out

Table 2. Nutrient requirements for maintenance and milk production of dairy cows of different livemass.

Live mass (kg)	Milk (kg)	Dry matter (kg)	ME (MJ)	DCP (k)
350	10	9.8	89	765
	20	10.8	138	1285
	30	11.8	188	1805
400	10	11.0	94	780
	20	12.0	143	1300
	30	13.0	193	1820
450	10	12.3	98	790
	20	13.3	147	1310
	30	14.3	197	1830
500	10	13.5	103	800
	20	14.5	152	1320
	30	15.5	202	1840
550	10	14.8	108	805
	20	15.8	157	1325
	30	16.8	207	1845

Dry matter intake is derived from the relationship DMI = 0.025M + 0.1 Y where M = livemass in kg and Y = yield of milk in kg. ME for maintenance is taken as 487 KJ/$M^{0.75}$; ME and DCP for milk production is taken from average Friesland Milk (36 g/kg butterfat and 86 g/kg solids non-fat) of 4.93 MJ ME/kg and 62 g digestible protein and 30 g of tissue protein/ kg (Topps and Oliver, 1993).

Table 3. Least-cost diet formulation derived using the Excel spreadsheet incorporating different leaf meals.

Component	Control	Leaf Meal (% composition)				
		C. calothyrsus	***L. pallida***	***L. diversifolia***	***L. esculenta***	***A. angustissima***
Maize	66.58	51.83	50.23	51.38	55.15	55.87
Cottonseed cake III	35.02	29.63	7.28	4.19	0.90	22.07
Leaf meal		17.13	41.09	43.02	42.55	20.66
Vitamin-Mineral premix	1.40	1.40	1.40	1.40	1.40	1.40
Total	100	100	100	100	100	100
Crude Protein %	16.00	16.00	16.00	16.00	16.00	16.00
ME (MJ/kg)	12.35	11.00	11.00	11.00	11.00	11.00
Cost ($/kg)	0.34	0.30	0.25	0.25	0.25	0.29

ME = Metabolisable Energy content in Megajoules per kilogram dry matter.

for all leaf meals shown in Figure 1: *C. calothyrsus, Leucaena pallida, Leucaena diversifolia, Leucaena esculenta* and *Acacia angustissima*. The resultant least-cost formulations using this method including all leaf meals presented in Figure 1 are shown in Table 3.

Normally the conventional commercial dairy meal concentrate consists on average of 16% CP and 11 MJ ME/kg DM energy content represented by the "Control" column in Table 3. This is a typical dairy meal concentrate for a high yielding cow in mid-lactation. The inclusion levels for the leaf meals range between 17% for *C. Calothyrsus* to 43% for *L. diversifolia*. The inclusion levels for *L. pallida* and *L. esculenta* are greater than 40%. With higher levels of legume inclusion, there is a corresponding reduction in levels of cottonseed meal to be used. Maize meal inclusion is also reduced. As a result the diets with the Leucaena spp inclusion are the least-cost.

Managing the feeding programme

Successful feeding of the dairy cow should aim to deliver the correct amount of nutrients needed to meet the individual cow's requirements. The normal recommend-dation is that a cow should be fed 0.4 kg dairy meal concentrate per litre of milk produced for yields below 15 kg/day (Dunham, 1989). The assumption behind this recommendation is that the forage part of the diet would have taken care of the maintenance requirements plus roughly about 5 kg/day of milk production. Taking an example of a 350 kg cow giving a milk yield of 10 kg, reading off values from Table 2, the animal would need 89 MJ ME and 765 g DCP. At 0.4 kg dairy meal concentrate per litre of milk produced recommendation, the cow should be given 4 kg of dairy meal concentrate. The dairy meal concentrate fraction therefore would supply 44 MJ ME and 360 g DCP. The animal will be in deficit by 45 MJ ME and 405 g DCP. The deficit in a normal feeding programme should be supplied through the forage part of the diet. In most instances this will be average quality maize silage with 10.5 MJ/kg DM ME and 8.1% CP content (Table 1). About 22 kg (5 kg dry matter basis) of average quality maize silage should be able to cover for this deficit.

For those compounding complete rations however, the method proceeds as follows:

1. Determining nutrient requirements of the animals (Table 2).
2. Determining forage intake. It is recommended that maize silage should be fed at 5 kg per 100 kg body mass per day (Webster, 1993).
3. Calculating nutrient supply from forages
4. Determining nutrients needed in the dairy meal concentrate mix and formulating the dairy meal concentrate using the procedure outlined in this paper. Care must be taken that the ration is not too bulky that the animal will not be able to consume all the feed.

However, since farmers always buy dairy meal concentrate which they use at 0.4 kg per litre of milk produced, the exercise in this paper has concentrated on formulating a diet that approximates to the dairy meal concentrate.

DISCUSSION

Feed formulation, in a dairy enterprise is critical to the success of the enterprise since feeding makes up 60 - 80% of the variable costs in milk production (Webster, 1993). The critical nutrients to balance for include protein, energy, minerals and vitamins (Pond et al., 1995). These nutrients are normally provided in the dairy meal concentrate portion of the diet. In addition the farmer needs to minimise the feeding costs. Commercial dairy producers in most cases buy already formulated “ready to feed” dairy meal concentrates and then feed their animals according to manufacturers’ recommendations.

In the smallholder dairy sector of sub-Saharan Africa, farmers cannot buy the commercial dairy meal concentrates due to the prohibitive costs and lack of availability especially since the structural adjustment embarked upon by many of the economies (Jera and Ajayi, 2008). These smallholder farmers have a number of feed resources available on the farm or in their locality which they can incorporate into the feeding programme. A substantial number of farmers in east and southern Africa have also adopted the growing of multipurpose forage legumes for use in dairy production. In southern Africa, farmers normally harvest the fodder legumes in the wet season, dry them and incorporate them in complete rations in the dry season (Chakoma et al., 2004). The major problem however facing the smallholder dairy farmers under these circumstances is how to optimise the mix of the different ingredients available on-farm to meet the animal’s nutrient requirements.

This paper describes a process of using a spreadsheet programme to achieve this objective. The process proceeds by establishing a database of feed ingredients available to the farmer including the chemical composition and cost; defining the animal requirements; constructing equations and finally computing the diet using the SOLVER function in excel®.

A number of workers, for example Pesti and Seila (1999) and Thomson and Nolan (2001) have advanced the use of the spreadsheet programme for tertiary education teaching of ration formulation. However, the use of the spreadsheet programme as advanced by these workers requires that the user download pre-programmed databases with inbuilt equations. This limits the flexibility and level of control the user has over the process. Farmers in different circumstances are working with different feed ingredients, having different chemical compositions and cost and also following different animal production systems altogether.

The method presented in this paper presents the user total control over the whole diet formulation process. The user can choose the ingredients to work with, vary their chemical composition in light of any new information, fix their inclusion levels in the diet if need be, change the ingredient costs depending on the prevailing market prices, select specific animal nutrient requirements depending on circumstance and then carry out the diet formulation process as many times as necessary depending on the feed ingredients available at each point in time. This is a big advantage over software packages which are delivered pre-programmed as they compromise on flexibility and give the user limited control in the diet formulation process. The process as described in this paper has been simplified to such an extent that any user with basic knowledge of Excel® will be able to implement the formulation exercise without difficulty. The methodology is suitable for extension workers working with smallholder dairy farmers or farmers themselves who would be having a number of ingredients available on farm which they can home-mix for feeding their dairy cows.

It should be noted however that the SOLVER in Excel® spreadsheet can be used for the production of practical diets for any livestock species. The extension worker is able to quickly formulate diets to meet given farmers’ requirements. Even if SOLVER does not give a good solution, through the process of iteration however, it will give the next best formulation, which will be much better than “guesstimates”. In most smallholder dairy systems, some of the milk bulking groups own a computer used largely for record keeping. The farmers can employ a technical person who among other duties can advise them on nutritional management of their dairy cows. The method demonstrated here can make a huge difference in the profit level of the dairy enterprise.

In the exercise carried out in this paper, five forage legumes, *C. calothyrsus, L. pallida, L. diversifolia, L. esculenta* and *A. angustissima* were incorporated to achieve 16% CP and 11 MJ/kg DM ME in the dairy meal concentrate portion of the diet. This diet approximates to the dairy meal concentrate offered to cows in mid-lactation. Due to the quality of the forage legumes (high CP and digestibility) the SOLVER function managed to converge to a solution. In fact, all the Leucaena species can be included at levels of over 40% while *C. calothyrsus* can be included at 17%. In terms of inclusion level, the forage legumes can be ranked as *L. diversifolia* > *L. esculenta* > *L. pallida* > *A. angustissima* > *C. calothyrsus.* The *Leucaena* spp inclusion diets were the cheapest. The cost reduction varied from 10% on *C. calothyrsus* inclusion to 30% on *L. diversifolia* compared to the conventional dairy concentrate costing US $ 0.34/kg (Table 3). The *Leucaena* species have been associated with higher protein content and higher in vitro dry matter digestibility. In addition, they have lower levels of anti-nutritional factors (Dzowela et al., 1997).

From studies conducted in Zimbabwe, when *A. angustissima*, *C. calothyrsus* and L. leucocephala were incorporated in complete rations for dairy cows, they gave respective yields of 11.6, 8.6, 14.4 kg/day compared to 15.6 kg on the control diet based on conventional cottonseed meal concentrate (Hove et al., 1999). However, long-term studies on the effects of using the legume forages in production rations need to be carried out.

Smallholder dairy farmers throughout sub-Saharan Africa have at their disposal a number of feed ingredients normally classified as “non-conventional”. Examples include poultry litter, brewers grains, maize bran, orange peels, banana stalks, sunflower seed cake and sunflower heads. These ingredients can easily be incorporated into the dairy meal concentrate fraction of dairy cows using the method described in this paper and will significantly reduce the feed cost bill to the farmer. This will be a real option to the purchase of ready to feed dairy meal concentrates by farmers.

Conclusions

Commercially available protein concentrates are prohibit-tively expensive for the smallholder dairy farmers in sub-Saharan Africa. However, these farmers have a number of locally available feedstuffs at their disposal that can be used for home-mixing into the dairy meal concentrate fraction. The Excel® spreadsheet programme through the use of SOLVER function can easily be adapted for use at the farm level or by extension workers to compute diets that are balanced for key nutrients and also being least-cost. In most cases, extension workers working with smallholder dairy farmers have access to computers and can offer a service to smallholder dairy farmers through formulating specific diets depending on the feed ingredients which will be available to the farmers.

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