Simple decision support for feed planning

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This article highlights some old and new approaches that may be useful in assisting livestock-dependent people to meet their production objectives through the planning of diets and/or feeding strategies for their animals. It first describes the initial application of mathematical techniques based on linear programming (LP) using the simplex method or its derivatives. It explains that, although these simple applications have proved to be very effective in situations where one objective (generally profit maximization) is regarded as being overarching, they are of little use to livestock owners who keep their animals for multiple uses. Moreover, LP applications cannot identify near-feasible solutions that in many instances may be adequate for the user and more cost-effective. Although these drawbacks have been addressed by using a number of different approaches, each with its own merits, no single approach has been extensively adopted. Recent increases in desktop computing power and user-friendly software interfaces may, however, call for a re-evaluation of some of them.

The article also points out that the computer-based applications of mathematical programming techniques that are currently available require an availability of data and a degree of sophistication on the part of the user that are unlikely to qualify them for field use in developing countries. The final section of the article, however, describes two recent innovations for the delivery of animal nutrition biology in a format that is both user-friendly and effective. The first of the methods described is the Dairy Rationing System for the Tropics (DRASTIC), which was developed with the objective of producing a genuinely usable, decision support tool for planning dairy feeding under tropical conditions. DRASTIC has a user-friendly design, it requires no expert knowledge of nutrition and the nutritional variables in the underlying model are assessed from simple indicators of feed quality, allowing the system to cope with variable feed compositions in the absence of quantitative data. Use of DRASTIC in an interactive mode with farmers in the field has shown that it can be very effective in predicting outcomes and designing modified feeding strategies for more cost-effective production or increased yield. Nevertheless, DRASTIC still relies heavily on frequent contacts between extension systems, which are often functioning inadequately, and farmers. Deficiencies in this process may mean that the outputs produced by such tools as DRASTIC will not always be sufficiently responsive to changing conditions. The article then explains how the need to generate information that reduces the complexity of the interaction between extension services and farmers and allows farmers to take a more active part in the evaluation of alternative strategies has led to the development of Talking Pictures. This is a dynamic pictorial system that represents the nutritional management of dairy cows in smallholder farming systems. The tool builds on the principles used in the development of DRASTIC, using this software to generate hard-copy guides in an easily understood pictorial format consisting of several pictorial input layers that incorporate genotype, condition, stage of lactation and physiological status, calf rearing system, and quantity and quality of feed inputs (basal and supplements) that are dynamically linked and that provide pictorial answers for the expected production outputs. Although still under development, the initial evaluation of the Talking Pictures methodology in the field has shown encouraging results.

The article concludes with some remarks that underline the continuing rapid development and spread of computer technology in the world, which is likely to generate considerable practical benefits in the further development of simple decision support for feed planning.

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INTRODUCTION

Farmers enter all agricultural activities with a specific production objective or objectives in their minds or business plans. In the production systems of the developed world, in the past such objectives have generally been relatively simple ones based almost exclusively on profit maximization. More recently, the needs of many households in the developing world where integrated crop-livestock farming is practised have been recognized as more complex than this. These farmers must balance objectives that relate to a wide range of livelihood issues such as food security, risk aversion and environmental sustainability, in addition to maximizing levels of production. In many parts of the world, even the managers of more industrialized production systems must now take account of considerations related to the environmental impact of their activities and the need to limit production levels so as not to exceed quotas or market capacity. A range of decision support methodologies, including those based on operations research techniques, have been studied as a means of assisting farmers to specify objectives and to plan more effectively. A number of these have even found widespread practical application in a production context.

Livestock production is no exception in requiring decisions to be made that relate to the generation of specific outputs from available inputs. This article considers some of the approaches that may be used in different situations to assist livestock managers to plan diets and/or feeding strategies that will allow them best to meet their production objectives.

MATHEMATICAL APPROACHES TO FEED PLANNING

The widespread application of mathematical techniques to feed planning was first made possible about 25 years ago by the advent of powerful microcomputers capable of conducting the calculations required by the mathematical programming algorithms that are used for this purpose rapidly.

The best-developed of these methods for ration formulation is based on linear programming (LP) using the simplex method or its derivatives. In general terms, LP has been used for a wide range of applications when it is necessary to identify the combination of values for a set of decision variables that will minimize (or maximize) the value of the objective function that the combined values make up. In addition to the objective function, an LP model will have a set of constraints which place limits on the acceptable values of the decision variables. Thus a typical LP model for cost minimization in diet formulation takes the form:

Decision variables:	$i_1 \ldots i_n$
	Inclusion levels of n available feeds
Objective function:	$c_1.i_1 + \ldots + c_n.i_n = C$
	Total cost of the ration (C) as the sum of the products of the costs (c) and inclusion levels (i) of the n available ingredients
Example constraints:	$p_1.i_1 + \ldots + p_n.i_n > P$
	The sum of the products of the protein contents (p) and inclusion levels (i) of the n available ingredients must be greater than the protein requirement (P) specified for the ration
	$i_1 < I_1$
	The level of inclusion of ingredient 1 (i.e. the value of decision variable) must be less than the level (I) specified for the ration.

In a situation where a wide range of raw materials and nutritional supplements are available, LP techniques are very effective in identifying the optimum combination of feeds that will produce a nutritionally adequate diet at least cost. Apart from assigning a concrete value to the variables in the objective function, the algorithm may also be used to generate information for ranging and sensitivity analysis that allows the robustness of the solution to be assessed. For example, if the cost of an individual ingredient increases, the price at which its continued inclusion ceases to represent part of the optimum (i.e. least cost) solution may be recognized.

However, in an unmodified form, simple LP applications suffer from at least two major limitations:

- They are unable to cope with multiple objectives. This is not generally considered to be a problem when profit maximization is regarded as an overarching objective. However, if further objectives must also be met, a least-cost ration formulation derived by LP will give no indication of the impact of this solution on other enterprises on the farm. It would therefore be of little use in instances where livestock are kept by their owners for multiple uses such as the provision of draught power and manure in addition to meat or milk.
- They cannot identify near-feasible solutions, which in many practical situations may be deemed adequate by the producer. This is a more general limitation and relates to the assumption that the nutritional specifications of diets are absolute and clearly defined. Individual animals of a specified type are highly variable in their responses to nutrients, so a diet that is not optimal for one animal may be perfectly adequate for another. In addition, slight underspecifications to an optimized LP solution may reduce ration costs considerably at the expense of an intangible reduction in level of production. Such a solution, however, would be deemed unfeasible by a LP algorithm and would not be identified.

In order to address these difficulties, alternative mathematical programming techniques have been suggested. Rehman and Romero (1984) considered a number of possible approaches based on multiple criteria decision-making models (goal programming, lexicographic goal programming and multiple objective programming). The authors concluded that each of these approaches could offer benefits which ranged from the opportunity of making a systematic exploration of trade-offs among the different optimization criteria offered by the goal programming techniques to the possibility of using multiple objective programming to identify a set of contrasting optimal solutions that can be further evaluated for practicality by the user. The use of goal programming with penalty functions, suggested by Rehman and Romero (1987), revolves around replacing the rigid constraints required by simple LP with goals that are associated with a penalty function. Thus, for example, if the goal related to a minimal value for a nutrient in the formulation is not quite achieved, the solution is not rejected as unfeasible. Whether or not it is optimal will be determined by the extent of the penalty that has been assigned to not achieving that goal and the extent to which the solution falls short of the goal. The authors claim, with justification, that this approach makes "the specification of minimum nutrient levels more flexible and realistic".

These approaches have not found widespread application, perhaps owing in part to the limitations of computer hardware when they were first suggested.

With the considerable enhancement of desktop computing power since the mid-1980s, and the availability of programming tools for the rapid development of user-friendly software interfaces, it is perhaps time for a reassessment of the practical possibilities of these approaches to ration formulation.

THE PARTICULAR NEEDS OF DEVELOPING COUNTRIES

While mathematical programming techniques, in their various guises, offer wide flexibility in feed planning, they do have a serious limitation for use in practical feed planning in developing countries. Mathematical programming algorithms are based on a relatively rigid, deterministic statement of the problem addressed - in this case a biological description of the relationships between the nutrient inputs to and the productive outputs from farm livestock. As a result they are not easily adapted to situations where data are few and/or unreliable, as is almost invariably the case in developing countries when working close to the farmer in a decision support capacity. Tropical feeds are highly variable in quality and the need for the specific, quantitative information required to run these algorithms is unlikely to be met by underresourced extension services. In addition, practical decision support tools for developing countries must be simple to apply and flexible enough to account for multiple, varied and frequently changing objectives. The computer-based applications of mathematical programming techniques that are currently available require an availability of data and a degree of sophistication on the part of the user that makes them inappropriate for field use.

SOME RECENT INNOVATIONS

Two recent innovations aim at delivering the biology of animal nutrition to front-line extension services through developing services in realistically usable formats. These approaches avoid the complexities of incorporating a specification of farmers' objectives within the software package. However, they may be used in such a way that farmers' existing knowledge of nutritional interactions - which recent research suggests may be highly sophisticated (Thorne *et al*., 1999) - can be used during an interactive and iterative process of feed planning.

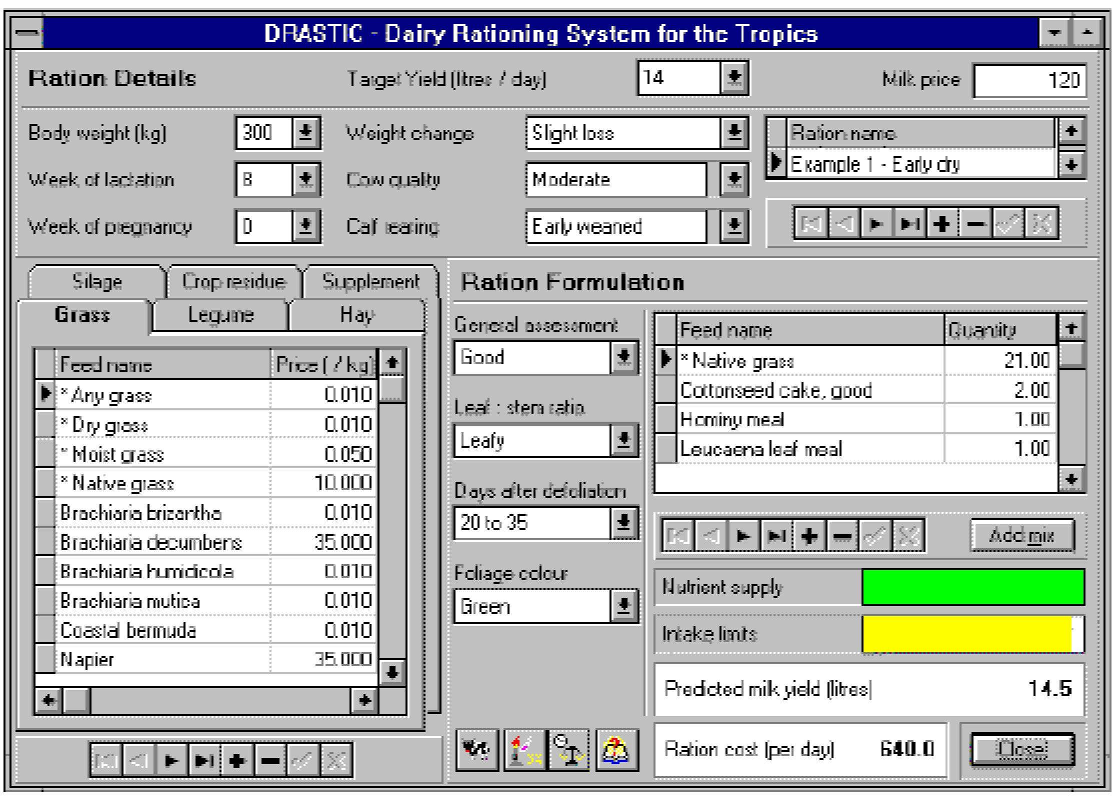
DRASTIC

The Dairy Rationing System for the Tropics (DRASTIC) (Thorne, 1999) was developed with the objective of producing a genuinely usable, decision support tool for planning dairy feeding under tropical conditions. A major problem of rationing cows under these conditions is the lack of information on the nutritional quality of available feeds - particularly of the basal ration. This is compounded by a high degree of variation in feed quality that makes routine chemical analysis or reliance on "book values" for composition of little practical use.

The following key requirements were addressed during the development of DRASTIC:

- It has a user-friendly design (Figure 1).
- No expert knowledge of nutrition is needed to use it.
- Nutritional variables in the underlying model are assessed from simple indicators of feed quality (Table 1), allowing DRASTIC to cope with variable feed compositions in the absence of quantitative data.

Figure 1
The DRASTIC predictions were used as a basis for identifying improved supplementation strategies for enhancing the actual milk yields on these trial farms.



The DRASTIC user interface has been designed to be intuitive and simple to use.

Table 1
Qualitative indicators used by DRASTIC for assessing the nutritive value of basal diets

Indicator	Allowable values	Used for

General, subjective quality assessment by the farmer or extension officer	Very poor, poor, moderate, good, very good	Grasses, legumes, silages, hays, crop residues
Leaf-stem ratio	Very stemmy, stemmy, stem = leaf, leafy, very leafy	Grasses, legumes, silages, hays, crop residues
Days after previous defoliation by grazing or cutting	More than 45, 35 to 45, 20 to 35, 7 to 20, fewer than 7	Grasses, legumes
Colour of foliage	Yellow, greenish yellow, yellowish green, green, deep green	Grasses
Pest damage	More than 70%, 35 to 70%, 10 to 35%, less than 10%, no damage	Legumes
Odour	Nauseating, very acrid, slightly acrid, musty, sweet	Silages
Apparent moisture content	Very moist, moist, normal, dry, very dry	Silages, hays, crop residues
Length of chop	Not chopped, long chop, medium chop, short chop, fragmented	Hays, crop residues

In order to address these issues, DRASTIC formulations access the whole range of variability observed in tropical feeds. The software is supplied to the user with the nutritional data that are required to run the core model for a range of commonly used tropical feeds, including supplements. For basal feeds, both maximum and minimum values are provided for each variable. The user, in conjunction with the farmer who will use the formulation, must then apply the set of qualitative indicators (summarized in Table 1) to the feeds that are currently available. These indicators are used to prime an artificial intelligence algorithm (essentially a fuzzy model adopting the approach described by Thorne, Sinclair and Walker, 1997). This then generates data in order to run a biological simulation of protein and energy nutrition - modified from the standard approaches proposed by AFRC (1993) - that predicts the outcome, in terms of milk production achieved, of using a particular mix of feeds.

Use of DRASTIC in an interactive mode with farmers in the field has shown that it can be very effective in predicting outcomes and then designing modified feeding strategies for more cost-effective production or increased yield. In particular, trial use in Bolivia (Table 2) was effective in illustrating the outcomes of increased supplementation in feeding systems based on native pastures. DRASTIC may be downloaded, free of charge, from www.stirlingthorne.co.uk/drastic.html

Table 2
Examples of the use of DRASTIC with a group of cattle farmers in Bolivia[1]

Farmer	Actual milk yield *(litres/day)*	Yield predicted by DRASTIC *(litres/day)*
Eduardo	20	19.1
Fidel	15	15.4
Fito	8	8.2
Juan	12	9.9

Miguel	8	7.9
Oscar	8	7.9
Rosendo	15	14.5
Toto	8	7.4
Yapacani	8	7.3

[1] The DRASTIC predictions were used as a basis for identifying improved supplementation strategies for enhancing the actual milk yields on these trial farms.

TALKING PICTURES

The lack of effective linkages among research, extension and farmers is a global problem. Particularly in recent years, when climatic changes combined with a reduction in access to natural resources resulting from significant population increases have called for major changes in the traditional methods of animal management, neither indigenous knowledge systems nor existing advisory mechanisms have been able to keep pace with the rate of change required.

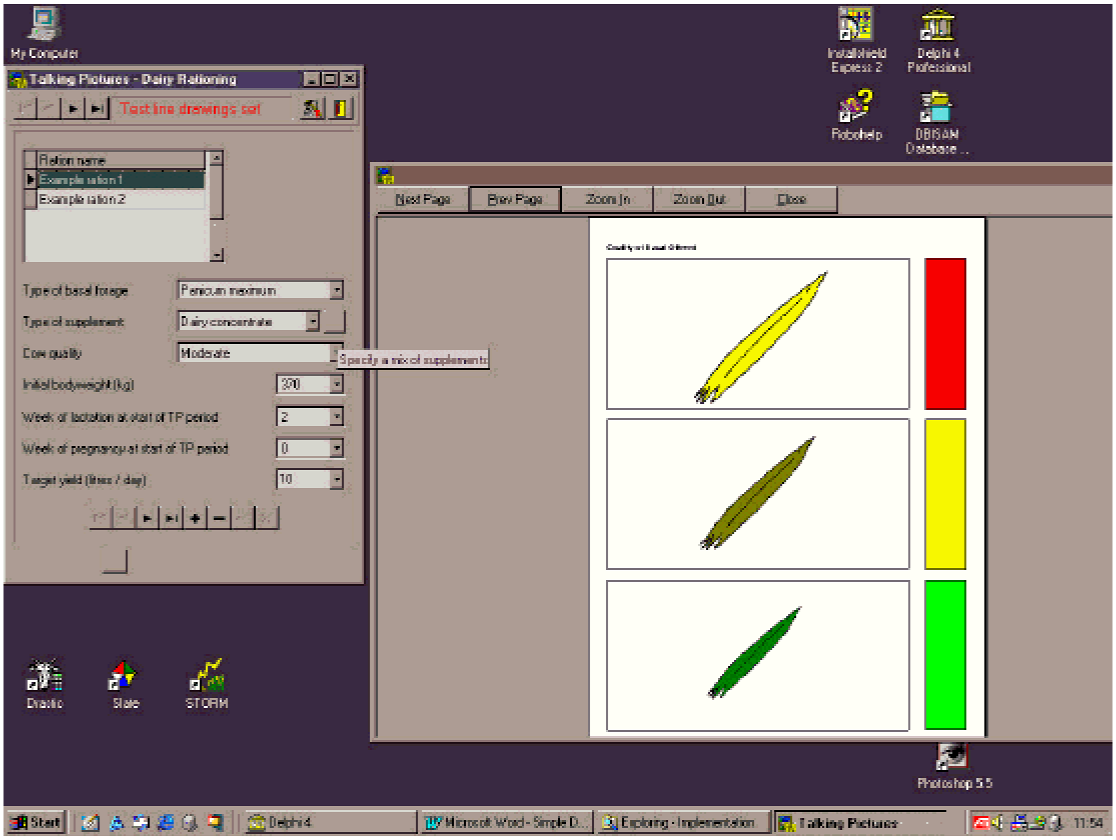
Although much effort has been spent on improving communication among stakeholders, most research results are still delivered in a format that is difficult to comprehend and assimilate by extension workers, who are generally not experts in the particular subject area (Greenland *et al*., 1994; Moris, 1991; Østergaard, 1994). Without the effective implementation of this link, it is difficult to see how extension services can promote improved feed management among their client-farmers in a way that is flexible enough to meet individual needs and that accounts for the dynamics of feed resource availability in smallholder systems.

Paper-based extension literature, in tabular or other formats, is not easily assimilated by extension staff who are not generally experts in nutrition. The development of DRASTIC directly addresses these problems, but DRASTIC still relies heavily on frequent contact between extension systems, which are often poorly functioning, and farmers. Deficiencies in this process may mean that the outputs produced by such tools as DRASTIC will not always be sufficiently responsive to changing seasons, resource endowments, local markets and production objectives, compromising the extent to which farmers can base their management decisions on these and other factors.

There is, therefore, an additional need to generate information in a form that reduces the complexity of the interaction between extension services and farmers, and that allows farmers to take a more active part in the evaluation of alternative strategies. This is particularly important for such enterprises as dairying, in which changes in activities on a daily basis can influence production in the short term. Static recommendations prevent farmers from adapting effectively to short-term changes in resource availability and production levels. In response to this need, the development of Talking Pictures has taken the scientific information on dairy nutrition packaged by DRASTIC and used it to generate a methodology for presenting it dynamically to farmers in an easily understood pictorial format.

The Talking Pictures concept. Talking Pictures is a dynamic pictorial system used to represent the nutritional management of dairy cows in smallholder farming systems. This computer-based tool builds on the principles used in the development of DRASTIC, using the DRASTIC software to generate pictorial guides in hard copy (Figure 2). The hard copies consist of several separate pictorial layers that incorporate genotype, condition, stage of lactation and physiological status, calf rearing system, and quantity and quality of feed inputs (basal and supplements), which are dynamically linked and provide pictorial answers for the expected production outputs, costs and income.

Figure 2
The Talking Pictures user interface displaying a preview page for estimating basal diet quality taken from a set of Talking Pictures based on simple line drawings



The A4 hard-copy guides are produced in such a way that users can choose one of three options, appropriate to each specific animal, for each of five pictorial input layers, i.e. lactational and physiological status; condition; calf rearing system; quality of the basal diet; and quantity of the basal diet (Figure 3). Each option is either colour- or pattern-coded, depending on whether colour or black-and-white printers are used to generate the hard-copy guides. The pattern or colour for each of the chosen input layer options is transferred with dry-wipe markers to a reusable laminated "credit card", leading to a unique sequence of five colours or patterns. This sequence is matched to the appropriate sequence out of 243 possibilities, supplied on three pages and linked to a pictorial representation of the expected production level for the animal in question. Based on this, users turn to the appropriate supplementation page, indicated by the picture of the expected production level (Figure 4). On these pages, users can select from different pictorial representations of supplementary feeds and different levels of supplementation, which are connected to a picture of the total milk production expected. Each of the supplementation choices also supplies pictorial data on the ratio between milk and concentrate prices at which supplementation of the chosen quantity becomes profitable.

Figure 3
Example of a Talking Pictures input variable for animal condition

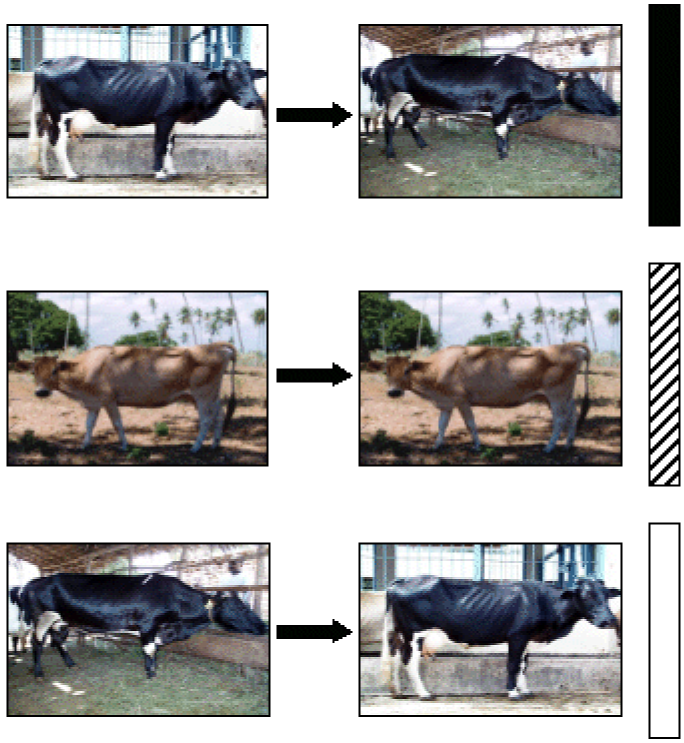
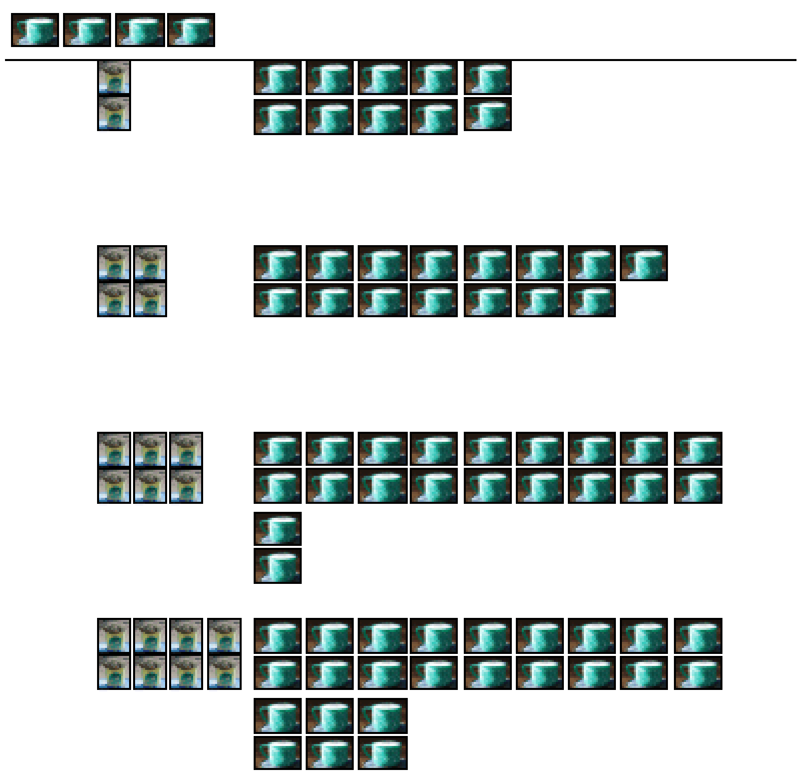


Figure 4
Example of a Talking Pictures supplementation page



Participatory development and use of Talking Pictures. The guides can be prepared for specific areas and situations because, prior to the generation of hard-copies (as booklets or posters), pictures of the appropriate cow genotype, calf rearing systems, recognizable quantities of feed and milk, types of concentrates, etc. can be selected from a thumbnail library which is linked to the appropriate biological data in the DRASTIC software. To enable this development of area-specific Talking Pictures, an appropriate thumbnail library will have to be collected. This requires the determination and testing of unit sizes/weights for basal diets, supplements and milk, as well as universally recognizable pictorial representations of calf feeding systems, stage of lactation/physiological status and conditions, and farmers' perceptions of fodder quality.

The methodology is currently undergoing further refinement, and a standard protocol for the rapid collection of pictorial indicators is under development. Nevertheless, experiences during the elaboration of the prototype in the United Republic of Tanzania and Kenya show that the variables are collected easily and rapidly through a number of participatory exercises and that identical unit sizes to measure concentrates and milk are used over large areas. In addition, pictorial representations of calf rearing systems, stage of lactation, condition, fodder quality, etc. collected in the United Republic of Tanzania were readily interpreted by farmers in Kenya, indicating that many visual indicators used by farmers may be based on widely held common understanding. Moreover, although farmers had difficulty in estimating the actual weight in kilograms of recognizable units of forage (for example, bicycle load, head load, wheelbarrow load, etc.), they demonstrated great aptitude in the conversion between units and the comparison of pictures of different quantities of forage with the amount of fodder they provide to their animals.

A Talking Pictures prototype is currently undergoing field evaluation and initial results have indicated that the guides are accurate and user-friendly, for farmers and extensionists alike.

CONCLUDING REMARKS

The current rate of development in desktop computing facilities and their rapidly increasing distribution throughout the developed and developing regions have led to a considerable expansion in opportunities for delivering decision support in feed planning that is both effective and suitable for a wide range of circumstances. In addition, simple tools for the rapid development of graphical user interfaces means that there is no longer any excuse for this type of tool not to exhibit a substantial degree of user friendliness. This article has described some simple tools for decision support that demonstrate the range of possibilities from paper-based to computer-based feed planning, including the hybrid approach of Talking Pictures. Possible future developments are legion. As well as the application of the existing tools to other production systems - for example, DRASTIC is currently being adapted for use with draught cattle and oxen - the integration of optimization techniques, including those based on artificial intelligence approaches, is likely to generate considerable practical benefits.

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