Forage Master: A decision tool for selecting and managing forages for New Zealand sheep and beef farms

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Abstract
This paper describes the development of a forage selection decision tool. The project was carried out in conjunction with Meat and Wool New Zealand and farmer mentor groups in Manawatu, Canterbury and Southland. The model uses a multi-criteria technique called Electre III which helps rank the characteristics of forages relative to environmental conditions and farmers objectives. The approach allows farmers to rank and compare suitable species and cultivars. The decision tool provides advice on appropriate seed mixes and specific information on establishment and management. In addition the model was structured to allow farmers to discover limitations to their environment or management systems through a process called 'back-chaining'. An example of this is where a farmer queries the model to discover what conditions prevented a forage from being selected. Demonstrations of the Forage Master to a range of farmer groups nationwide has provided excellent feedback on the value of the decision tool, firstly for aiding on-farm decision making and secondly, benefits associated with the information provided in the help links.
Keywords: computer model, cultivars, forage, forage selection, multiple criteria, pasture species

Introduction
New Zealand pastoral agriculture is undergoing rapid diversification and intensification (Fraser 2000). This has been accompanied by the development and use of a large number of forage species and cultivars (Brown & Green 2003). As well as choosing between large numbers of potential forages, the choices farmers make are complicated, as forage selection typically requires consideration of a number of criteria.For example, forage yield is only one factor that might be relevant to a farmer. Perhaps equally important are timing of production, ease and risks associated with establishment, and the environment and management systems required for satisfactory performance.

There is a wealth of knowledge as to the best use of forages which is supplied to farmers regularly by seed retailers and also available in comprehensive textbooks such as *Pasture and forage plants for New Zealand* (Stewart & Charlton 2003). However, farmers find it difficult to collate accurate and unbiased information, and make educated conclusions to allow decision making to occur.

The multiple criteria farmers often need to consider are not easy to include in traditional decision tool frameworks that are primarily concerned with forage yield. Nor are there simple-to-use tools to make it easy for farmers to assess the relative importance of the criteria they use to make decisions.

This paper discusses the process of developing and testing the forage selection decision tool, and the features of Electre III that make it an improvement to previous methods of forage selection. In particular, the concept of outranking and the use of indifference and preference thresholds are presented.

The forage decision problem
Successful management of forages relies on a number of factors. Firstly, a farmer needs to understand the limitations of the environment in which the forage will be grown. Secondly, they need clear expectations of what the forage can achieve and thirdly, have the knowledge and expertise to establish and manage the forage appropriately. A programme to further the ability of farmers to achieve these objectives was designed and constructed by AgResearch as part of the Specialist Forage Systems project funded by Meat and Wool New Zealand.

A key aspect of the project was to develop close ties with the farmer mentor groups in the Manawatu, Canterbury and Southland. These mentor groups meet regularly to assist in the direction and development of the model. In discussions with these groups it quickly became apparent that forages perform multiple functions and must be suited to complex environments. Further, it was difficult to describe contribution of a forage to a farm plan using only a single criterion.

In this study forage selection was treated as a multiple criteria problem. A variety of techniques have been used to model similar problems. Two well known approaches are decision analysis (Edwards 1977) and the analytic hierarchy process (AHP) (Saaty 1980). Here we report the use of a multiple criteria technique called Electre III (Hokkanen & Salminen 1997; Roy 1991, 1996).

Scoring forage attributes

The forage species in this study have all been tested and are commercially available in New Zealand (Table 1). A tool, tentatively named Forage Master, was designed to identify appropriate species and rank them in terms of their suitability to the soil and climatic factors and management system of a farm. To achieve this it was necessary to define the forage species in terms of key attributes.

The attributes considered in the model include a forages suitability to be grown in different regions, tolerance to drought and poor drainage, and susceptibility to pests and diseases. These attributes are represented using an index score of 0 - 7. The scores are 0 (unsuitable), 1 (very low), 2 (low), 3 (medium-low), 4 (medium), 5 (medium-high), 6 (high) to 7 (very high). Seasonal yield (spring, summer, autumn and winter) and feed quality are defined similarly. If a paddock is irrigated it is assumed a forages tolerance to drought will not be relevant to the farmer.

Other attributes use a different scoring system. For example, a forages suitability to soil pH is defined relative to a minimum (pH_{min}) and a non-limiting level ($pH_{non-lim}$).One illustration of this for lucerne is discussed by Langer (1973) who outlines the preferred range of soil pH for establishing lucerne, with establishment being limited at pH 5.6. The suitability criteria of the decision tool states that if the soil pH is less than pH_{min}, the suitability score is set to zero. If soil pH is greater than $pH_{non-lim}$, the suitability score is assumed to be 1. For a soil pH greater than pH_{min} but less than $pH_{non-lim}$ suitability is calculated by linear interpolation. A suitability score for soil Olsen phosphorus (P) is also calculated in the same way.

The assignment of suitability scores for longevity (annual, biennial, short rotation and perennial) and ease of establishment and management are dependent on what the farmer requires from the forage. For example if a farmer wants to plant an annual, and a forage candidate is an annual, it receives a high suitability score for this attribute. If the forage is a perennial, it receives a low or even zero score, indicating it is less or perhaps unsuited to the farmer's requirements.

Forages are also defined in terms of whether they are easy, moderate or difficult to establish and manage. The farmer is then given the choice of whether the forage 'must be easy', 'can be easy or moderately difficult' or 'can be difficult'. Factors such as the availability of skilled labour, high quality machinery, ability to tolerate risk, and time available to perform operations are likely to influence the farmer's choice.

The remaining attributes in the model include

Table 1 Summary of forages included in Forage Master.

Forage class	Forage species
Grasses	Ryegrass (Annual, Biennial, Short Rotation, Perennial) Tall fescue Cocksfoot Bromes (Grazing and pasture) Timothy Phalaris Yorkshire fog Prairie grass Clovers (White, Red, Sub, Strawberry, Caucasian, Persian and Balansa)
Legumes	Lucerne Lotus major Birdsfoot trefoil Sulla
Herbs	Chicory Plantain
Brassicas	Swedes Kale Rape Turnip (leaf and bulb)
Cereals	Ryecorn Triticale Oats Wheat Barley Maize Japanese millet Sorghum

suitability for direct drilling and the intended use (hay, silage, set stocked, rotationally grazed, or break fed). Binary scores of 0 (unsuitable) or 1 (suitable) are allocated to these criteria.

Forages that score zero on attributes which are relevant to the farmer are not considered further. The forages that remain available for selection are included in a performance or suitability matrix. Table 2 provides an example of a performance matrix for 5 forages and 3 criteria. In Table 2, ryegrass has a relatively high suitability score for region and pH but does not perform well if the drainage is poor. When compared with tall fescue, ryegrass has a slightly higher suitability for the region, the same score for pH but a lower score for poor drainage. Even this simple example, therefore, shows how it can be difficult to decide which forage is the 'better' choice. The differential performance of forages in the performance matrix is used as the starting point for using a systematic method (Electre III) to make these choices.

Electre III

The Electre III method was selected as it is efficient when comparing large numbers of alternatives. The technique also requires that indifference and preference thresholds, are specified which make it well suited to fuzzy or uncertain decisions (Rogers & Bruen 1998a, 1998b). Another attractive feature is it is non-compensatory. This means a very poor score cannot be compensated by good scores on other criteria. Lastly Electre III allows for incomparability when there is no clear evidence to differentiate one alternative from another.

Another difference is that in traditional preference modelling even small differences between alternatives can translate to differences in preferences. This contrasts with Electre III where the decision maker might be indifferent to small differences. The Electre III method also includes a buffer zone where a decision maker hesitates between indifference (I) and strict or strong preference (P), this allows 'weak preference' to be shown.

To achieve a ranked list of alternatives, the Electre III method tests the strength of arguments for and against the proposition. The arguments for involve evaluating a weighted sum of differences between the criteria for each pair of alternatives. The weights referred to here are estimates of the relative importance of different criteria and can be set by the model user. Alternately arguments that are against the proposition, are calculated in terms of a veto threshold.

Figure 1 Forage & cultivar selection.

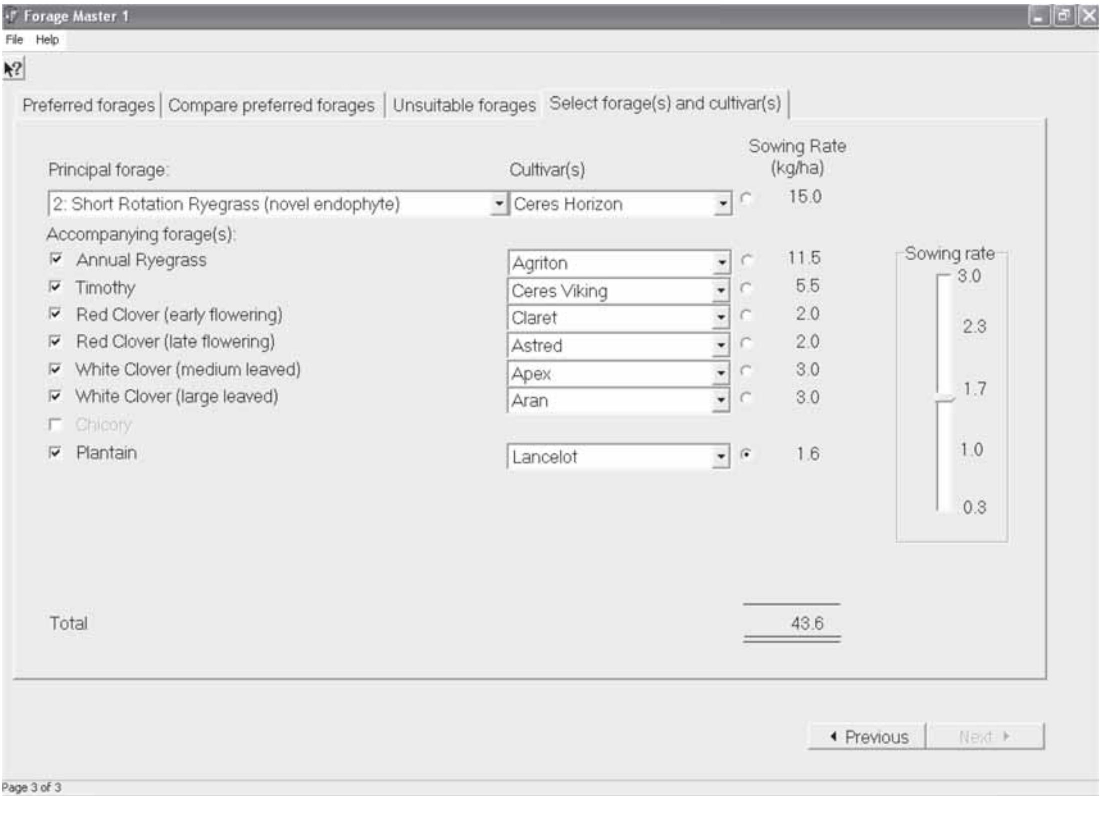


Table 2 Example of a performance matrix.

	Suitability to region	Tolerance to drainage poor	Suitability to pH
Ryegrass	6	2	1
Tall fescue	5	4	1
White clover	6	3	1
Plantain	4	5	1
Swedes	2	4	0.3

The measures of for and against are combined into a credibility matrix to assess the strength of the assertions for each criteria and forage. The final part of the process is to rank the forages using the credibility matrix. This provides the model user with a list of forages ordered in terms of their suitability to the environment and the farmer's objectives. In the following section the utility of the approach is illustrated with examples from the Manawatu, Canterbury and Southland. The results for these examples are included in Table 3.

It should be noted the ranked list given by the model reflects recommendations as to the ability of different forages to do well in the specified environment and meet the farmer's objectives. An assumption of the model is that any crop included in the recommended list can be grown; however, forages that are low in the order are unlikely to perform as well as forages that are ranked higher.

Figure 1 provides an example of a farmer selecting short rotation ryegrass (novel endophyte) as their preferred principal or primary species. The farmer can also select from a list of commercially available cultivars. The cultivars in the model are listed in alphabetical order and no attempt has been made to rank cultivars that have the same functionality. For most forages; the farmer has the option to select additional or accompanying species, such as legumes and herbs, to include in planting mix. The accompanying species are also screened in terms of suitability, and other than longevity, are screened on the same criteria as the principal species.

Example 1: Manawatu

In this example a farmer in the Manawatu wants a biennial forage. Additional information is the farm is irrigated and has drainage problems. Soil pH is 5.6 and Olsen P is 23 µg/ml. The manager is not concerned about difficulty of establishment or management and conventional tillage will be used. The pests and diseases that have been a problem in the past include grass grub, argentine stem weevil and ryegrass staggers.

The numerical scores the manager attaches to the priorities (weights) for seasonal yield in spring, summer, autumn and winter are 100, 90, 90 and 10, respectively.

Table 3 Example of Forage Master outputs.

Manawatu	Canterbury	Southland
1 Chicory	1 Tall Fescue (summer active, nil and novel endophyte)	1= Annual ryegrass, Rape (winter), Leaf turnip (winter)
2 Short rotation ryegrass (novel endophyte)	2= Perennial Ryegrass (novel endophyte),	4 Kale (single graze)
3 Biennial ryegrass	Tall fescue (winter active, nil and novel endophyte)	5 Biennial ryegrass
4 Short rotation ryegrass (nil endophyte)	4 Phalaris	6 Kale (double graze)
5 Red clover (late flowering)	5 Cocksfoot	7 Swedes
6 Red clover (early flowering)	6 Grazing brome	8= Rape (summer), Leaf turnip (summer)
	7 Timothy	10 Triticale (autumn)
	8 Perennial ryegrass (nil endophyte)	11 Bulb turnip
	9 Lotus	12= Oats, Ryecorn, Triticale (spring), Wheat
		16 Barley

The overall weights for forage yield are 100, forage quality 80, pest and disease tolerance 20, ease of establishment 20 and ease of management 20.

Example 2: Canterbury foothills

In this example a farmer in the Canterbury foothills decides on a perennial forage with a minimum longevity of five years. Their land is not irrigated and neither does it have drainage problems. The soil pH is 5.7 and Olsen P is 22 µg/ml. The manager is not constrained by any specific difficulties in relation to establishment and management and conventional tillage will be used.

The farmer wants to set stock the paddock in spring, rotationally graze in summer and autumn and break feed in winter and also wants the flexibility to conserve feed at times of surplus. The farmer is conscious that pests and diseases have caused problems in the past; in particular grass grub, argentine stem weevil and ryegrass staggers. Further parameters include the selected weightings for seasonal yield in spring, summer autumn and winter of 100, 50, 73 and 10 respectively. The priorities for forage yield are 100, forage quality 80, ease of establishment 25 and ease of management 30.

Example 3: Southland

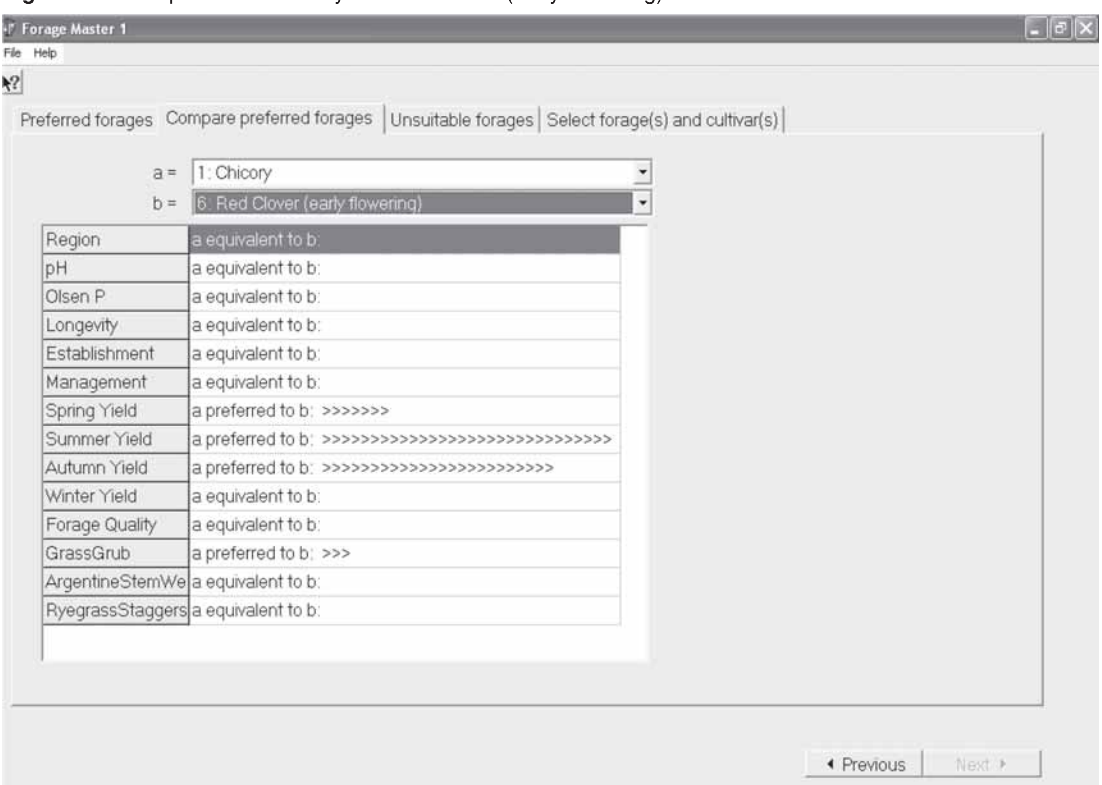
In this example a property in Southland selects an annual forage. The farm is not irrigated but it does have drainage problems. Soil pH is 5.5 and Olsen P is 25 µg/ml. The manager is not concerned about difficulties associated with establishment and management and wants to establish the forage using direct drilling. The farmer needs the forage for a single grazing as winter feed. Pests and diseases that have previously been a problem include aphids and club root. The manager's priority for winter yield is 100, and he is not concerned about yield in any other season. The overall priority for forage yield is 100, and for forage quality 50, pest and disease tolerance 30, ease of establishment 20 and ease of management 20.

Results and discussion

The ranked list of species produced for these examples are presented in Table 3. From these examples it can be seen the model can be applied to very different situations.

The model doesn't require farmers to select the top ranked forage. Rather the user has the opportunity to select the species they prefer. Alternately, the farmer can query why species are ranked as they are by using the

Figure 2 Comparison of chicory and red clover (early flowering).



'compare' function, or why other species are excluded using the 'unsuitable' function. An example of the user querying why one crop is ranked higher than another is included in Figure 2. This figure relates to the Manawatu example where the farmer wants to plant a biennial forage. In this example it can be seen that chicory is likely to perform similarly to red clover (early flowering) on most attributes or criteria. However, chicory is likely to perform slightly better in tolerating grass grub and in spring yield. Moreover, chicory is likely to yield significantly better in summer and autumn.

The user can also query the model why a forage is deemed unsuitable for a particular use or environment. With reference to the Manawatu example, Figure 3 shows that Bulb turnips were excluded as having unsuitable longevity (it is an annual and the farmer requested a biennial) and neither is it suited to rotational grazing.

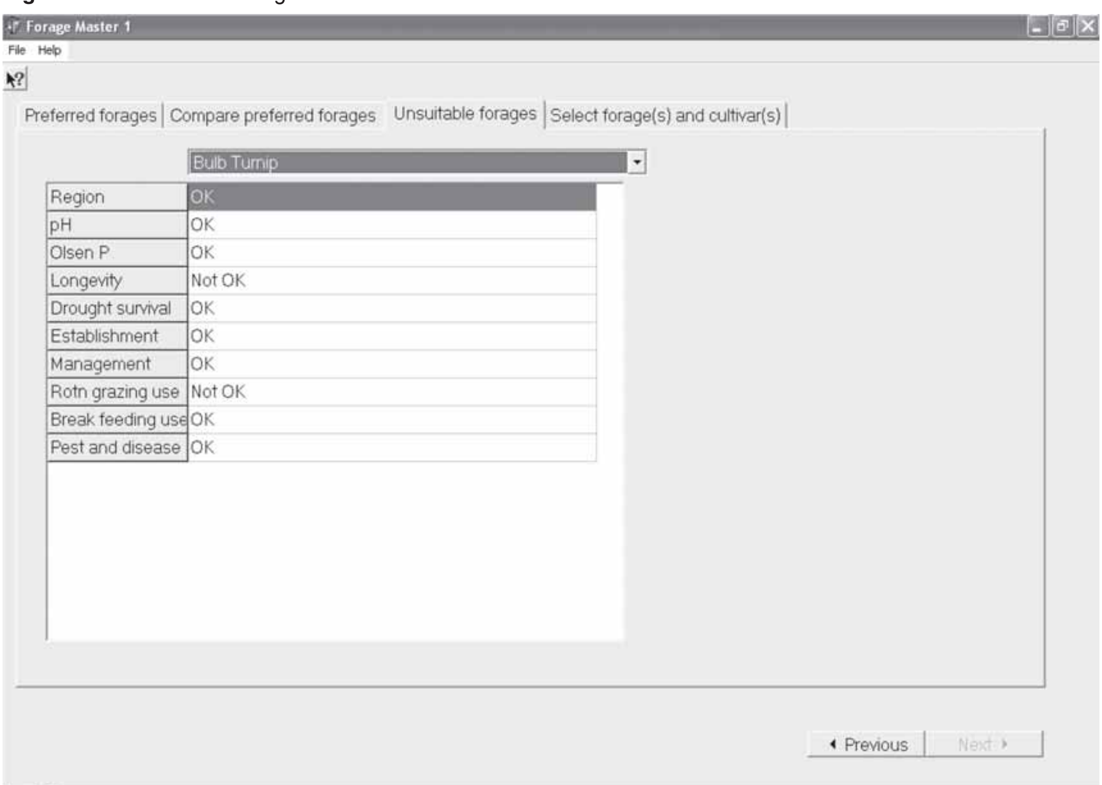
The three farmer mentor groups along with key industry personnel have been utilised to test and critique the decision tool. There has been a huge amount of interest from the farming community to the development of this particular model. Feedback has been very supportive of the independent approach and use of farmer mentor groups for both the design and testing of the model.

Conclusion

Forage Master has been designed and tested with the aid of three farmer mentor groups to produce a farmer-friendly, tool for assisting forage selection decisions. An important feature of Forage Master is it allows farmers to ask why one forage might be preferred to another. This lets farmers test the model interactively and explore variations in the weights or the importance they attach to different criteria. It also allows farmers to closely consider their management. For example, can the forage's environment be altered by providing fertiliser, irrigation, drainage or pest and disease control? Alternately does the farmer have options as to how they use a feed?

By raising these questions the tool allows farmers to clarify their understanding of their farm environment and objectives. The model is structured to analyse the information given by the farmer and provides a ranked list of suitable forage species. The programme also identifies suitable forage mixes that can be planted and suggested planting rates. Detailed help files are provided to assist in the decision making process, the material for

Figure 3 Unsuitable forages.



these files has been adapted from *Pasture and forage plants for New Zealand* (Stewart & Charlton 2003). The help files provide links to a range of topics including descriptions of the forages, issues relating to animal health and endophyte status, and information on establishment and management of each forage, to give farmers the confidence to use the forages proposed by the decision tool.

Forage Master is also valuable for collating standard information about the wide range of forages available to farmers. The accuracy of the model predictions have been evaluated by comparing model predictions against expert judgement. The evaluation process has involved a range of individuals and organisations that specialise in systems research, plant breeding, seed production, consultation, agronomy and farming. It is our aim to make a version available on the internet, where it can be updated as new species and cultivars become available. The tool has the potential to be invaluable in forage selection and management and represents a significant technical advance over existing methods.

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