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**"A Knowledge-Based Decision Support System
for Planning Reforestation Projects
in Developing Countries:
A Geographic Information System"**

By Gebrekiduce Mekonnen
B.A. Management
M.A. Public Administration

A Thesis Submitted to the
Faculty of Graduate Studies and Research
in Partial Fulfilment of the Requirements
for the Degree of

Master in Management Studies

School of Business
Carleton University
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A KNOWLEDGE-BASED DECISION SUPPORT SYSTEM FOR PLANNING
REFORESTATION PROJECTS IN DEVELOPING COUNTRIES:
A GEOGRAPHIC INFORMATION SYSTEM

submitted by Gebrekiduce Mekonnen, B.A., M.A.
in partial fulfilment of the requirements for
the degree of Master of Management Studies

Thesis Supervisor

Director, School of Business

Carleton University

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It can be argued that the management of reforestation projects in developing countries lacks the **skills** that are required to **produce and implement plans** which explicitly consider the variables that affect the success of the activity. As suggested by Mann & Ruth (1992), computerized knowledge-based systems (KBS) can improve this condition by making expert knowledge easily accessible in these countries. The planning of reforestation, particularly through social forestry, can be facilitated through knowledge-based decision support systems which incorporate social forestry and reforestation expertise. Moreover, reforestation exhibits properties that are desirable to build a KBS: (a) it is based on well known principles, procedures and techniques (Kamweti, 1982), (b) expert knowledge of the subject available in the literature and from human experts, and (c) the variables that affect the activity are fairly well known (Kamweti, 1982; Weber & Stoney, 1986).

Current reforestation DSS are limited in number and do not focus on the needs of developing countries. They mainly focus on specific problem areas (e.g., selection of land compartments to be reforested, use of fire for site preparation, etc.) to further improve the reforestation work in (developed) countries that have already achieved high levels of reforestation successes. On the contrary, the

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CHAPTER 1

1.1 Introduction

In developing countries, the sharp decline of forest area is threatening the sustainability of human and animal life. Land clearance for agriculture and settlements, increased household consumption of wood products and commercial logging are among the major causes of the decrease in the tree cover.

Reforestation is one of the most widely used measures to replace the depleted tree stocks. Beginning in the early seventies, many developing countries demonstrated interest in the activity and hundreds of *forestry development projects* worth millions of dollars were launched mainly with the aid of international donors (Leach & Mearns, 1988).

However, the accelerated decline of the tree area testifies that the projects did not improve the situation. Many were abandoned and many more did not achieve desired results (Blair & Ulpadwala, 1988). Projects have generally failed to: assess the ecological and socio-economic environment, articulate the purpose of the projects, evaluate trees, assess land tenure, and appraise the village capacity to plant trees (Raintree, 1991; Burley, 1982; Anderson, 1984; Jackson, 1984; Echolm, 1979; Mnzava, 1983).

It can be argued that the management of reforestation projects in developing countries lacks the **skills** that are required to **produce and implement plans** which explicitly consider the variables that affect the success of the activity. As suggested by Mann & Ruth (1992), computerized knowledge-based systems (KBS) can improve this condition by making expert knowledge easily accessible in these countries. The planning of reforestation, particularly through social forestry, can be facilitated through knowledge-based decision support systems which incorporate social forestry and reforestation expertise. Moreover, reforestation exhibits properties that are desirable to build a KBS: (a) it is based on well known principles, procedures and techniques (Kamweti, 1982), (b) expert knowledge of the subject available in the literature and from human experts, and (c) the variables that affect the activity are fairly well known (Kamweti, 1982; Weber & Stoney, 1986).

Current reforestation DSS are limited in number and do not focus on the needs of developing countries. They mainly focus on specific problem areas (e.g., selection of land compartments to be reforested, use of fire for site preparation, etc.) to further improve the reforestation work in (developed) countries that have already achieved high levels of reforestation successes. On the contrary, the

general failures of reforestation projects in developing countries demonstrate that success depends on the appraisal of important social, ecological and economic factors and the application of tree planting know-how, to an acceptable level.

This thesis presents the design a knowledge-based reforestation decision support system (KB-RDSS) which incorporates key elements of a reforestation process. The system aids the decision maker to: (a) acquire, retrieve and select site information, (b) structure reforestation activity such that choice alternatives are visible, and (c) suggest feasible planning alternatives. The paper has been organized as follows: chapter two presents the research phases in which the paper is divided; chapters 3&4, phase I, **analysis and planning**, introduce reforestation and discusses its failures and problems; chapters 5,6&7, phase II, **design**, break down reforestation into sequential decision making steps and present the design of how they can be accomplished; Chapter 8 describes the construction of a prototype using a reforestation case; and finally chapter 9, concludes with the expected benefits and limitations and further developments of the system.

CHAPTER 2

2.1 Research Methodology

This section outlines the research method that has been adopted to develop the KB-RDSS. Before dealing with the methodology however, some key concepts underlying DSS and KBS are presented briefly.

2.2 Decision Support Systems and Knowledge-based Systems

A DSS, despite the ongoing debate regarding its meaning, purpose and content (e.g., see Bosman, 1987:25-26), can be viewed as a computer based information system which supports unstructured or non-repetitive decisions. It provides the decision maker with methods, procedures, models, data bases, decision rules etc., to channel his/her cognitive processes towards better decisions than when unaided by such a system (Turban, 1990; Vlek et al., 1993).

Conventional DSSs are made up of three major parts (e.g., see Turban, 1990): (a) a data management module - which includes a database(s) and a database management system (DBMS), (b) a model management module - which can include various types of models (statistical, management science, etc.) and a software to manage them, and (c) a dialogue module - which interfaces the decision maker with the DSS.

Vlek et al., (1993) propose that decision support address three major activities of decision making: (a) acquiring, retrieving, and/or selecting relevant information, (b) structuring the decision problem such that choice alternatives become visible, and (c) evaluating alternatives for their relative merit.

Unlike a DSS, which supports decision making through computational and statistical models (Duda and Shortliffe, 1983), a KBS is a computer based expert which resolves (or supports the resolution of) problems regarding a specific domain of expertise (e.g., diagnose a patient, recommend a pesticide, etc.). ESs are heuristics-based and are particularly viable for problems that cannot be solved algorithmically (Writzel and Kerschberg, 1989). Generally, a KBS consists of six components (Jackson, 1992): (a) knowledge base - which stores the domain knowledge, usually in the form of IF-THEN rules, (b) inference engine - a logical deduction method that processes the knowledge to provide responses, (c) working memory - memory space which contains intermediate states of the knowledge base at a particular time during an ES's execution, (d) explanation subsystem - which illustrates how the response was reached, (e) knowledge acquisition subsystem- which aids a knowledge engineer in capturing expert

knowledge, and (f) user interface - the communication link between the user and the KBS.

Even though KBS can be built using artificial intelligence (AI) programming languages such as LISP and PROLOG or high level languages such as Pascal, most of them are built employing ES shells (Jackson, 1992). ES shells essentially consist of a knowledge representation scheme and a ready made inference mechanism (Jackson, 1992).

Geographic information systems (GIS) expert system shells (e.g., see Leung & Leung, 1993) are ES shells that assist in building ESs that deal with spatial decision making problems. They are used to develop KB-GIS. A GIS is a computerized database management system for the capture, storage, retrieval, analysis and display of geographically referenced data (Simkovitz, 1988). Even though a GIS can perform the above mentioned operations effectively, its conceptual, human intelligence and analytical capabilities have been found to be limited (Leung & Leung, 1993). KB-GIS overcome these limitations by incorporating qualitative data and expert system reasoning capabilities.

There is an increasing trend to integrate KBS and DSS (Liberatore & Stylianu, 1995). Systems that integrate intelligence into DSS are known as *knowledge-based DSS* (fig. 1). According to Pfeiffer & Luthi (1987), the inclusion of a knowledge base which complements the database with the knowledge of domain expertise, adds a new dimension

Figure 1 A knowledge based decision support system

to the DSS approach. It enhances modelling capabilities of the user by including appropriate ES-type models in the DSS (Pfeiffer & Luthi, 1987; Bonczek et al., 1981; Belew, 1985). Since ESs provide domain expertise, a DSS equipped with similar facility has the reasoning capabilities of an ES.

When decisions are related to the geographical conditions of a location, a knowledge and GIS based decision support system provides a better decision making support (Kolli et al., 1993). The GIS can provide data input to both the knowledge base and the model base such as multiple criteria preferential modules (MCDM).

2.3 The Development Methodologies of DSSs and ESs

DSSs and ESs can be developed employing different methodologies such as systems development life cycle (SDLC) and prototyping (e.g., Schreiber et al., 1993; Siddal, 1990; Turban, 1990). Nonetheless, the more traditional *SDLC* or *phased approach* still dominates the rest and none has substantially broken away from it (Huws et al., 1992). Moreover, even though the organization and emphasis may change the tasks to be performed remain the same (Sage, 1991; Siddal, 1990; Turban, 1990).

Turban presents the development of DSS and ES in six and ten phases respectively (see table 1²).

Table 1: DSS and ES development phases

<u>DSS development phases</u>	<u>ES development phases</u>
1. analysis and planning	1. problem identification
2. design	2. system analysis
3. construction and testing	3. conceptual design
4. implementation	4. software and hardware selection
5. operation and maintenance	5. system design and construction
6. evaluation and control	6. system development
	7. rapid prototyping (which includes knowledge acquisition, knowledge representation)
	8. implementation,
	9. maintenance
	10. evaluation

The activities performed in the various phases of the respective systems evidence that all ES phases, except knowledge acquisition and representation, serve similar functions as corresponding DSS phases. In both cases, phase one deals with the investigation of the problem area. Also, design, software selection, testing, implementation, evaluation and maintenance are undertaken in both systems. Therefore, a KB-DSS can be developed by including knowledge elicitation and representation in the DSS development phases.

² For detailed explanation of the phases see Turban, 1990.

2.4 The Development of A Knowledge Based Reforestation Planning DSS

Since the KB-RDSS incorporates an ES within a DSS, its development methodology blends the development phases of both systems. Specifically, as explained earlier, it incorporates the knowledge acquisition and representation phase of an ES into the DSS development phases.

The scope of this paper is limited to analysis, design and coding. Moreover, coding is performed for a very simplified version of the design model. Fig. 2 outlines and describes what will be accomplished in each phase, briefly.

Figure 2 KB-RDSS development phases and activities

Phase I, **problem identification**, discusses reforestation as the measure that has been widely adopted to control the deforestation crisis but which is constrained by lack of adequate planning; it then reviews the literature to identify available reforestation DSSs and their shortcomings; phase II, **Conceptual Design**, presents reforestation as a decision making process which is executed in a number of sequential steps and provides a general model and specific designs for each step; finally, phase III, **Coding**, builds a prototype and illustrates its application employing a reforestation case.

In the prototype, first, all case data was entered into a (GIS) data base. Second, a limited program which sets site needs in a format that can be easily entered into the MCDM application was coded. Third, two sample rule bases for selecting people mobilization strategies (PMSTs) and plant protection methods (PMSTs), were developed after eliciting relevant knowledge from experts and the literature (see samples of knowledge elicitation decision tables that have been used in the appendix). Finally, the above mentioned tools were loosely integrated and a partial plan that includes a site niche, objectives, PMSTs and PPMTs produced.

PHASE I

CHAPTER 3

3.1 The Deforestation Problem In Developing Countries

Developing countries, particularly in arid and semi-arid regions, are in the midst of a deforestation crisis. While the area of forest in developed countries has stabilized (in some cases increased) that in developing countries is declining rapidly (table 2) with a 50% drop in the present century (Spears, 1984). Since most developing countries depend on their natural resources for survival, the loss of their tree cover will lead to severe hardships of food, fuel and shelter.

Table 2. Estimates of forest cover area and deforestation

Geographic region	No. of countries surveyed	Total land area (million ha)	Forest area (million ha.)		Annually deforested area (m.ha)	Rate of change (%) (1981-1990)
			1980	1990		
Africa	40	2236.1	568.6	527.6	4.1	-0.7
Asia	17	892.1	349.6	310.6	3.9	-1.1
L.America	33	1650.1	992.2	918.1	7.4	-0.7

Source: Singh, 1993

To control deforestation, it is important that available techniques be studied and implemented effectively. Several agencies, particularly the UN and the World Bank, have proposed and implemented several techniques. A brief description of the UN's control measures is presented next.

3.1.1 Measures Against Deforestation

Various measures have been proposed to contain deforestation. In 1982, the UN recommended the preservation of 10% of existing forests, introduction of sustainable farming systems, **reforestation of degraded lands with fast growing trees for fuelwood and industry**, restriction of new settlements and the increase of financial and technical assistance in agroforestry.

More recently, the United Nations Environmental Programme (1994) proposed the following measures as *important* to fight desertification (which may directly result of deforestation):

- Recommendation 1: The introduction of improved land use systems which, among others, includes **undertaking major afforestation/reforestation campaigns**;
- Recommendation 2: The development and introduction of appropriate agricultural and pastoral technologies;
- Recommendation 3: The establishment of adequate communication infrastructure and sufficient processing and marketing facilities;
- Recommendation 4: The development and introduction of improved water management systems; and
- Recommendation 5: The reclamation of strongly desertified lands.

Among the proposed measures, reforestation accounts for the largest proportion of projects being implemented to control deforestation (Grainger, 1990). In the 1970s, environmental concern with deforestation and successive oil shocks resulted in an explosion of forestry projects (Blair and Ulpadwala, 1988). Attempts were made to establish large-scale fuelwood plantations of fast growing trees to meet the increasing need

of wood, especially for fuel (Grainger, 1990). In the late eighties, there were over 130 forestry development projects in place slated to spend more than \$US750 million in external grants and loans from eleven international donors (Blair and Ulpadwala, 1988).

3.2 Reforestation: Meaning, Approaches and Purposes

Even though more elaborate definitions have been provided (e.g. see Wiersum, 1984), reforestation can be defined as the re-establishment of the tree cover of an area devoid of or sparsely populated by trees, using indigenous or exotic trees.

Reforestation is generally undertaken in two major approaches, depending on the purpose(s) to be achieved: (a) *plantation forestry* and (b) *social forestry*. *Plantation forestry* (also known as industrial or commercial forestry) deals with the establishment of large scale plantations to restore and maintain forest areas and woodlands and to plant watersheds and shelter belts for erosion control and for the production of fuelwood and lumber. Generally, plantation forestry is predominantly market oriented (Anderson, 1984; Gregerson & MacGaughy, 1987; Mallik & Rahman, 1994). *Social forestry* (also known as community, village, farm or agroforestry) involves the planting and maintenance of trees and shrubs by farm

families near dwellings, as windbreaks, on the edges of cropland, in copses, and in small lots, sometimes in conjunction with crops (Gregerson & MacGaughey, 1987). It is a practice of forest management where local people participate in various ways to obtain a sustainable return from the forest (Mallik & Rahman, 1994).

The way reforestation is undertaken has major implications on its success (Hisham et al., 1991; Leach and Mearns, 1988). Until the early 1970s, almost all development forestry followed a northern model of large-scale, industrial-commercial plantations and top down natural forest management to earn revenues and foreign exchange (Leach and Mearns, 1988; Blair and Ulpadwala, 1988; Hisham et al., 1991). However, through the years, it became evident that this approach was neither ecologically nor commercially sustainable (Mallik & Rahman, 1994). The large-scale, top down approach and the image of forest departments and foresters as *resource cops* alienated rural people to the detriment of achieving sustained forest resources (Hisham et al., 1991). Moreover, the institutional support and the resource base to manage and fund large-scale forest plantations was usually beyond the reach of less developed countries (Leach and Mearns, 1988).

By the mid 1970s, with the emergence of a people-centered (basic needs, participatory approach) development paradigm, the practice of social forestry gained public support. Mass participation obtained at grass roots level, reduced the needed infrastructure and funding significantly (Leach & Mearns, 1988). Many donor agencies also supported the initiative (Mallik & Rahman, 1994). For example, in the 1980s, the World Bank spent 60 percent of its forestry budget on agroforestry projects, whereas in the 1970s, 95 percent of its spending had gone to industrial large-scale plantations (Leach and Mearns, 1988).

Even though social forestry projects should be people centered, rural poor generally lack resources and time to initiate them (Ahlbäck, 1995). A common problem in social forestry is therefore mobilizing the people concerned (Ahlbäck, 1995). According to Ahlbäck, mobilization can be effected in three ways: (1) **encouragement** through education and incentives, (2) **coercion** through compulsion to plant trees, and provision of the right to plant trees, and (3) providing the **means** through technology, resources, and institutions (village authority).

3.2.1 Purposes of Reforestation

As could be noted from the definitions of social forestry and plantation forestry, the aims of reforestation are mainly conservation and production (Weber & Stoney, 1986). Glesinger (1963) and Khan (1987) agree that besides conservation, reforestation should be planned to produce poles, pulpwood, fuelwood, fodder, essential oils or other minor economic forest products. Heth (1983) offers a succinct summary of the possible aims of reforestation:

"..to protect the soil from water and wind erosion; to protect settlements, industrial plants, and agricultural crops, by means of windbreaks, shelter belts, and woodlots; to provide some greenery and shade near settlements, and to create small copses of trees for recreation and tourism, to provide fuelwood, charcoal, some small timber for fencing and agricultural supports; to extract minor products such as tan bark, gums, oils etc.; as well as insure topfeed for livestock in drought years".

Agpaoa et al., (1975) provided an itemized list of objectives for tree planting or reforestation: (1) production of sawnwood, veneer and plywood, (2) production of pulpwood, (3) production of fuelwood, (4) production of poles and piles for local consumption, (5) production of *minor forest products* like rubber, fibers, tannin, resin, fruits, etc., (6) erosion control, (7) protection and improvements of watersheds, (8) shelter belts and (9) beautification.

Raintree (1991) provided the most comprehensive list of ecological and socio-economic benefits of trees, which can be

considered the possible objectives of a reforestation project. He classified and presented the benefits under products and services as illustrated in table 3².

Table 3: Reforestation objectives

PRODUCTS	SERVICES
FOOD (for people)	LIVE FENCING
Fruits	Dense hedges
Nuts	Stickwood fences
Oils, etc.	Posts, etc.
FEED (for livestock, fish, etc.)	WIND SHELTER
Leaves	Shelter belts
Fruits, etc.	Windbreaks, etc.
ETC.	ETC.

Source: Raintree, 1991.

3.3 Reforestation Management and Its Problems in Developing Countries

It is widely recognized (e.g., Mann & Ruth, 1992; Jeager, 1990; Kiggundu, 1989) that developing countries face a unique organizational and managerial environment. Distinct socio-political and economic problems facing these countries require that management evaluate its decisions accordingly. To design effective reforestation planning strategies therefore, the investigation and classification of reforestation problems should be done within the context of the organizational and managerial conditions of these countries.

² For a complete list of objectives see, Raintree, R. John; Socioeconomic Attributes of Trees and Tree Planting Practices. FAO/ICRAF, Rome, 1991.

Kiggundu (1989) classifies the organization and management problems in developing countries according to the pyramidal structure of the activities (decisions) of an organization:

- (1) strategic management tasks (strategic decisions),
- (2) middle management (semi-structured decisions), and
- (3) critical operating tasks (operational decisions).

At the strategic level, developing country organizations fail to formulate clear statements of mission and a clear sense of purpose and direction (Kiggundu, 1989). Similarly, a major problem in reforestation has been the failure to assess the ecological and socio-economic environment in which trees are grown and then articulate the purpose(s) of the projects clearly and accurately. Lack of preliminary research, lack of relevant data to evaluate trees, failure to assess land tenure, failure to match village capacity with project requirements have been typical problems (Raintree, 1991; Burley, 1982; Anderson, 1987; Jackson, 1984; Echolm, 1979; Mnzava, 1983).

At the middle management level, organizations in developing countries are characterized by: weak management system and controls, inadequate management and administrative skills, and lack of specific industry knowledge and experience (Kiggundu,

1989). These same problems have plagued reforestation through; inadequate supervision, failure to apply correct timing of planting, failure to replace dead plants, and failure to determine optimum size of nursery plants for field establishment (Anderson, 1984; Jackson, 1984).

At the operational level, developing country organizations experience weak boundaries of unprotected technical core and inefficient high cost operations (Kiggundu, 1989). That is, management fails to support the uninterrupted performance of key day to day activities because of the disruption of the supply of energy, raw materials, cash and the failure to protect organizational assets. Likewise, reforestation projects have suffered severe setbacks from projects abandoned prematurely due to excessive costs, sudden budget cuts, and unprotected trees - from agents such as heat, wind, animals, humans and weeds (Jackson, 1984; Blair and Ulpadwala, 1988; Anderson, 1987; Goudie, 1990; Morgan and Moss, 1990).

Reforestation is also required to achieve multiple and often conflicting objectives. Trade-offs have to be made among the various ecological and socio-economic goals of the activity (Kangas, 1992). Reforestation projects in developing countries however, have repeatedly failed to elicit the multiple needs

of villagers focusing instead on exclusive objectives such as fuelwood and timber (Mnzava, 1983).

Increased complexity, conflicting demands and the need of advanced skills in management in general and natural resources management in particular, have led to the adoption of advanced decision making techniques and computer based decision support systems (Dykstra, 1984; Kangas, 1993). While many applications have been implemented successfully in the developed world, it has been suggested that the introduction of computerized support systems, particularly knowledge-based systems, in developing countries would play an important role in the process of effective decision making (Mann & Ruth, 1992). This is particularly relevant in reforestation in which multiple demands, large quantities of data and expertise of subject matter are required. Before proposing a KB-DSS for reforestation however, the review of current reforestation DSS literature is of particular relevance. The review will examine the relevance of the systems to reforestation decision making in developing countries and is expected to provide an empirical and theoretical foundation to the proposed system.

CHAPTER 4

4.1 Current Models and Support Systems for Reforestation

Decision support for reforestation is of a very recent origin. Publications dealing with, or closely related to the topic, mainly appeared in the 90's. Moreover, most of them focus on some rather than on all aspects of the task.

Out of the thirteen articles reviewed, only two (Kangas, 1992 & 1993) consider the various activities in a reforestation operation. Others (Carlowitz et al., 1993; Webb et al., 1984; Jorgensen et al., 1991; Johnston et al., 1993; Marathe et al., 1991; Marz, 1993; Booth, 1988; Booth, 1991; Workantin et al., 1992) are limited to specific tasks such as tree selection and site preparation. The remaining articles (Kolli et al., 1993; Jankowski & Richard, 1994; Leung & Leung, 1993) deal with software techniques (e.g., integration of MCDM with GIS; use of GIS for facility scheduling and routing) that are relevant to the proposed KB-DSS and not reforestation as such.

Based on the models and the type of support that is described, the articles can be divided into four categories:

(a) Analytic models:

i. which support reforestation objective determination; mainly the analytic hierarchy process (Kangas, 1992; Kangas, 1993),

ii. which computes the tree mix to be planted; a quantitative model which includes statistical (tree usage frequency) techniques (Marz, 1993),

iii. which support routing, facility location and land use analysis; models which integrate GIS and multi criteria decision making (Kolli et al., 1993; Jankowski & Richard, 1994).

(b) Expert Systems:

i. which supports the selection and espacement of trees; a rule-based ES (Workantin et al., 1992);

ii. which supports fire site preparation; a rule based ES (Johnston et al., 1993); and

iii. which supports the development of GIS-based expert systems; FLESS - a GIS ES shell (Leung & Leung, 1993).

(c) Data bases:

i. which support tree species selection (Webb et al., 1984; Marathe et al., 1991; Carlowitz et al., 1993; Booth, 1991);

(d) Simulation model:

i. which supports the selection of site compartments to be reforested; simulated annealing (Jorgensen et al., 1993).

Next, each of the above mentioned models is described briefly.

a. Analytic Models

i) Analytic Hierarchy Process (AHP)

The AHP has been used extensively in various multiple-objective planning applications (Golden et al., 1989; Zahedi, 1986). The method employs decision alternatives and the criteria through which the alternatives are evaluated. A subjectively defined weighting mechanism assigns numerical values to both criteria and alternatives to finally achieve a prioritized list of alternatives.

To solve a decision problem using the AHP, the following steps are followed (see Zahedi, 1986 and Kangas, 1992):

1. Structuring the decision problem into a hierarchy of interrelated elements (objectives);
2. Performing pair wise comparisons at each level of the hierarchy to determine which element is more important and how much more important;
3. Computing the relative weights of elements at each level of the hierarchy using the eigenvalue method. The global weight of each element determines the relative importance of that element (or objective); and
4. Using the relative weights, determining the set of ratings of the decision alternatives.

At step one, the decision maker breaks down the decision problem (e.g., reforestation) into a hierarchy of interrelated objectives. The bottom most level constitutes the decision alternatives.

At step two, pairwise comparisons are made at each level of the hierarchy. A scale of measurement which ranges from 1-9 is provided to perform the preferences of pairwise comparisons (see Golden et al., 1989). To perform the pairwise comparisons, a matrix of criteria or objectives is constructed. In matrix A, need $n_{ij} = 1/n_{ji}$ for all $i, j = 1, 2, \dots, n$ (see Golden et al., 1989). If w_i is the weight given to n_i , then matrix A would appear as (see Kangas, 1992; Zahedi, 1986):

$$A = (n_{ij}) \begin{pmatrix} 1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & 1 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & 1 \end{pmatrix}$$

While comparing the criteria the question of which criterion is more important (e.g., ecological or socio-economic), and how much more important would be answered on the basis of the scale measurement of AHP. The relative importance of the criteria can be determined by an individual or a group.

At step three, using the pairwise comparisons as input, the vector of local weights or priorities $w = (w_1, w_2, w_3, \dots, w_n)$ would be estimated using the eigenvalue method. Saaty's eigenvalue method computes w as the principal right eigenvector of matrix A . Based on a consistent matrix A , relative weights could be determined by solving the equation:

$$Aw = \lambda w$$

where λ is the only non zero eigenvalue of a consistent matrix A ; w is its eigenvector (see Kangas, 1992). AHP also computes an inconsistency index of the weights assigned by the evaluator. As a rule of thumb, an inconsistency index of 10 percent or less is considered acceptable (Zahedi, 1986).

Once the local priorities have been determined, at step four, global priorities can be calculated downwards from the top of the hierarchy by multiplying the local priorities by the priority of their corresponding decision element at the level above and adding them for each element on a level according to the criteria it affects (Kangas, 1992). Finally, the global weights of the criteria are used to arrive at a set of criteria rated according to their size of weight. These, in turn, are used to evaluate and prioritize the decision alternatives.

Kangas (1992; 1993) provides the case of a non-industrial landowner who formulates a multiple-use plan of a forest area. He first develops a hierarchy of objectives (timber production, amenity value and impact on water) which represent the owner's decision criteria. An additive function which includes standardized values of the sub-objectives is then employed to determine the reforestation chain which maximizes overall utility of the landowner. While net present value is the standardized value for timber production, other sub-objectives for which standard values are computed are reforestation methods, tree species and soil preparation methods.

The landowner then assigns values of importance to sub-sub-objectives. For example, within the sub-objective of amenity value, the decision maker would compare and assign weights to reforestation methods of natural regeneration, seeding and planting. Within the tree species sub-objective he assigns weights to pine, spruce and birch. And within soil preparation methods he assigns weights to ploughing, harrowing and no site preparation. The additive function (which includes the standardized values of net present value and the other objectives) is then used to compute the overall utility of the

landowner for various chain alternatives. The chain with the highest value is then selected.

ii) GIS-based Multi criteria Models

Kolli et al., (1993) propose a DSS which integrates GIS and optimization methods for solving facility location, and routing and scheduling problems. The authors state that since facility location and logistics problems require large amounts of geographic data, they can be solved more efficiently with a spatial DSS based on GIS and optimization models. Moreover, such a system facilitates interactive decision making since graphic feedback, through GIS, is more meaningful.

The integration of GIS and optimization software is based on the data in the GIS and the data requirements of the optimization model. Whereas the mapping software helps to perform various spatial and data base operations, the optimization software is utilized to model, solve, and analyze decision problems. Optimization solutions are then stored in the GIS data base and presented in the form of maps and graphs through the GIS presentation module (fig. 3).

Figure 3 Integration of GIS with Optimization Model
Source: Kolli et al., 1993.

Jankowski & Richard (1994) describe a spatial DSS which integrates GIS-based land suitability analysis and multi-criteria evaluation (MCE) for route selection. According to the authors, while suitability mapping techniques do not accommodate political and economic priorities; multi criteria evaluation methods fail to consider physical conditions. Hence, the integration of the two results in better decisions. The GIS-based land suitability analysis and multi criteria evaluation are integrated in seven steps as illustrated in fig. 4. ARC/INFO and BEST CHOICE software are integrated through the *loose coupling* strategy; which is a file-exchange mechanism with independent GIS and MCE user interfaces. User interface is invoked with a batch file that opens the main menu:

1. GIS ANALYSIS IN PC-ARC/INFO
2. MCE IN BEST CHOICE
3. QUIT

ENTER MENU CHOICE (1/2)

The choice of option 1 opens the GIS analysis menu:

THE MCE-GIS SPATIAL DECISION SUPPORT SYSTEM

MAP VIEW

GIS ANALYSIS

CREATE MCE FILES

RESELECT FEATURES

HELP

MAIN MENU

The selection of option 2 brings up the menu:

- A. IMPORT GIS FILE TO BEST CHOICE
- B. EVALUATE LOTUS FILE IN BEST CHOICE
- C. IMPORT RESULTS TO GIS DATABASE
- D. MAIN MENU

ENTER MENU CHOICE (A/B/C) .

Figure 4 Integration of GIS with Multicriteria Evaluation Method

Source: Jankowski & Richard, 1994.

b. Expert Systems

Two ESs, an agroforestry planning system and a fire site preparation *effect prediction* system have been developed by Workantin et al., (1992) and Johnston et al., (1993) respectively.

Workantin et al.'s system, given data input such as rainfall, soil fertility, soil acidity, terrain slope and elevation; recommends the trees to be planted in agroforestry and their espacement. The knowledge base of the system includes (see tables 4&5): a probability system, which indicates varying degrees of success expected if the recommended technology is implemented; qualifiers (e.g., annual rainfall) which contain a key determinant and appear in the IF statements; qualifier value, a value (number, word or phrase) in the IF statement; probability value, numerical value assigned to the choice; decision rule, conditional statement which consists of facts and/or heuristics about the specified area; note, information which tells the user who, what, where, when, why and how something occurs.

Table 4: Qualifier data for an agroforestry ES

No	qualifiers	a	b	c	d
1	Annual rainfall	700-1099	1100-1600	>1600	
2	Number of rainy season/yr.	1(unimodal)	2(bimodal)		
3	Total rainy months/yr.	3.5	5-7	7-9	>9
4	Elevation	<500	500-1000	1000+	
5	Slope (%)	<15	15-29	30-39	>40
6	Soil texture	clay	loam	sandy	
7	Soil fertility	poor	medium		
8	Soil reaction (pH)	<5.5	5.5-7.5	>7.5	

Source: Workantin et al. 1992

Table 5: Production rules of an agroforestry ES

Production Rule	
IF	The approximate annual rainfall per year is low (700 to 1100m.)
and	The number of rainy seasons in a year is one (unimodal)
and	The average number of rainy months in a year three to five
and	The elevation/altitude of the field is (low) less than 500 m.
and	The predominant soil reaction is acidic (less than 5.5 pH)
THEN:	
	Plant <i>Leucaena leucocephala</i> (Lele) spaced less than 4 m. apart or spaced 4 to 6 m. apart or spaced 6m. or greater apart - Confidence = 20/100
and	Plant <i>Leucaena diversifolia</i> (Ledi) spaced less than 4 m. apart or spaced 6m. or greater apart - Confidence = 20/100
and	Plant <i>Cassia Siamea</i> (Casi) spaced less than 4 m. apart. Confidence = 20/100
and	Plant <i>Cassia Siamea</i> (Casi) spaced 4 to 6 m. apart or spaced 6m. or greater apart - Confidence = 50/100

Source: Workantin et al. 1992

The ES developed by Johnston et al., (1993) supports decisions that deal with the *prescribed burning* site preparation method. Given data of *growth limiting factors* (climate, vegetation, soil characteristics, topography, moisture conditions, and fuel (slash)), the system predicts the degree to which each factor will limit plant growth after treatment. Prediction of the treatment effect aids the evaluation of the productivity of the site to decide whether to apply the method.

The knowledge base of the system is decomposed into modules based on the growth limiting factors. The modules are invoked in a specific order (Fig. 5), as some of the growth factors affect others and have to be evaluated before those affected.

The knowledge of the growth limiting factors was structured in tables (see table 6) and rules generated on the basis of the tables (see table 7).

Table 6. Growth limiting factors

SOIL TEMPERATURE SLOPE-ASPECT	TABLE ADJUSTMENT FACTOR	
	Slope <= 20%	Slope > 20%
North-East	-1	-2
North-West	0	0
South-West	+1	+2
South-East	0	0

Source: Johnston et al., 1993.

Figure 5 Fire site preparation knowledge base modules.

Source: Johnston et al., 1993

Table 7: Site preparation ES production rules

RULE 1	IF Aspect = North-East AND Slope <= 20
THEN	Slope-Aspect Adjustment Factor = -1
RULE 2	IF Aspect = North-East AND Slope > 20
THEN	slope-aspect Adjustment Factor = -2
RULE 3	IF Aspect = North-West
THEN	Slope-Aspect Adjustment Factor = 0
RULE 4	IF Aspect = South-West And Slope <= 20
THEN	Slope-Aspect Adjustment Factor = +1
RULE 5	IF Aspect = South-West And Slope > 20
THEN	Slope-Aspect Adjustment Factor = +2
RULE 6	IF Aspect = South-East
THEN	Slope-Aspect Adjustment Factor = 0

Source: Johnston et al., 1993

iii. GIS based ES shell

Leung and Leung (1993), state that the effective usage of current GIS for decision making is constrained by inappropriate logical foundations and low level of intelligence. They argue that Boolean logic, logic on which current GIS are based, does not give room for impression in information and human cognition and is inappropriate for spatial analysis.

Leung and Leung (1993) thus developed a *fuzzy-logic-based* expert system shell (FLESS) which facilitates the construction

of rule-based geographical expert systems. Fuzzy logic is a non-standard logic within which an inference is a deduction of imprecise conclusions from a set of imprecise premises. For example:

Major premise: If temperature is high, then pressure is low.
Minor premise: The temperature in pixel X is quite high.
Approximate conclusion: The pressure in pixel X should be quite low.

FLESS consists of four subsystems:

a) **Knowledge acquisition subsystem;** which consists of (i) object management module: creates, modifies or deletes objects in the system. An object is a basic entity such as precipitation, slope, population etc., which possesses a number of predefined slots which specify its properties. The object management module provides routines to manipulate objects and their slots. (ii) Fuzzy terms management module: stores fuzzy terms about objects such as high, low etc., and supports operations such as create, delete, view, and print. (iii) Facts management module: obtains facts from either the user, a database or files. (iv) Rules management module: stores rules in a text file format. An external full-screen editor is used for entering and editing rules. (v) System properties management module: allows the user to input or change; the goal objects, the initial task objects, the inference mechanism (backward or forward chaining), the

inference formulae, outputs to the screen or file and the value of the rule-triggering threshold.

b) **Fuzzy knowledge base:** which stores knowledge entities such as objects, rules and fuzzy terms acquired through the knowledge acquisition subsystem.

c) **Consultation driver:** which consists of: (i) inference engine - supports both backward and forward chaining, (ii) linguistic approximation routine - maps the set of fuzzy subsets onto a set of linguistic expressions, (iii) review management module - traces rules and facts during consultation and provides explanations for why and how a conclusion was reached. It also handles WHAT-IF reviews which find out what conclusions will be deduced if certain facts are changed.

d) **Maps display module:** displays maps with imprecision using half-toning and colouring techniques.

c. Data Bases

Data bases have been developed to support the tree species selection process of reforestation. The first tree species data base to be developed was INSPIRE (Interactive Species Information Retrieval) by Webb et al., (1984). It is a data base from which trees are retrieved based on user requirements. Species data are listed under a total of 21 features. Selection is made by successively entering user's

requirements (feature values) and site conditions. The species selected are listed as either main (which meet all requirements) or marginal (which partly meet requirements).

A tree data base of indigenous arboreal flora of Western Maharashtra India has been developed by Marathe et al., (1991). The data base includes tree features such as ecological preferences (e.g., high rainfall, sandy soil etc.), habitat niches (e.g., hill slopes, salt swamps), and phenological aspects (e.g., fruiting months, leaf-fall months) and economic utility (e.g., medicinal, fuel, ornamental). The user can query the data base by forming any combination of attributes as per the requirement of a particular situation or habitat. For example, for a proposed plantation in salt swamp areas along a coast, different species can be listed with fuel and timber values.

Perhaps the largest tree species data is ICRAF's (International Center for Research in Agroforestry) Multipurpose Tree & Shrub Database (MTPS) developed by Carlowitz et al. (1993). It is a relational data base which contains information on more than 1,000 trees and shrubs. It runs on MDBS IV, which allows customer programming to meet their specific needs. It provides 19 selection criteria (see

table 8) to formulate the search string. Using a stepwise approach the number of species is concurrently reduced to reach a short list of the most likely species for the requested use or site conditions. The system also contains a library of species profiles and a seed directory for each tree. Once a selection has been reached, further assessment can be performed using the species profile.

Table 8: Tree species selection criteria

Tree selection Criteria:	
Koeppen codes	Salinity
Food	Soil classification
Fodder	Soil depth
Wood products	Plant Morphology
Utilities	Management
MPT services	Cultivation
Propagation	problems
Soil texture	Environmental
Countries	responses
Regions	Soil reaction
Water logging	

Source: Carlowitz et al., 1993

Another data base is the Climatic/Edaphic and Plant Growth Index Prediction geographic data base for Africa, developed by Booth (1991). It is a climate and soil database which indicates the suitability of a tree on more than 10,000 sites across Africa. Information describing the chosen plant's edaphic and climatic requirements is entered and color maps produced on the screen indicating edaphic, climatic and overall limitations for the particular plant. Limitations range on a 0-9 scale; 0 represents no limitations (i.e., most favorable condition) and 9 represents the greatest possible

limitation (i.e., the least favorable condition). A cursor is then moved over any location on the map and detailed model calculations examined for that location.

d. Simulation Models

A simulation model which defines and designs new forest compartments for reforestation has been developed by Jorgensen et al., (1992). The model uses simulated annealing to define and design new forest compartments on the given site. Given: (1) area constraint for each forest compartment, (2) total area constraint for all forest compartments, (3) GIS data from which potential afforestation areas are identified, and (4) qualitative user input, the system searches for the minimum convex polygon of potential afforestation areas.

Evaluation of the Models

An evaluation of the relevance of the DSSs for reforestation planning in developing countries is summarized in Table 9. On the basis of the evaluation, the following conclusions can be made:

a) almost all the systems deal with specific topics in reforestation, thus not providing any comprehensive plan of action,

b) there are no support systems which aid the compilation of site data to be used in reforestation decision making. The effective collection of such data is necessary for the identification of site problems, the formulation of objectives and tree data base query criteria, and making effective tree growing decisions,

Table 9: Evaluation the relevance of current DSSs for social forestry reforestation in developing countries

REFORESTATION DSS/ES	PURPOSE	REMARKS
Booth et al. (1988)	Climatic and edaphic representation of specific sites in Africa	Does not provide a socio-economic representation of site
Jorgensen et al. (1991)	Reforestation site selection based on bio-physical factors	Socio-economic factors not considered in site selection
Workantın et al. (1992) Webb et al. (1984) Marathe et al. (1992) Marz, U. (1993) Carlowitz et al. (1993) Booth (1991)	Concerned with the selection of trees taking physical, chemical, economic and some social conditions of site	None of the systems provides a systematic method of compiling and evaluating site data to be used in querying the tree data base
Johnston et al. (1993)	Concerned with the effects of "fire" site preparation method on the ecological, tree growth limiting, factors of a site.	In arid climates, general measures such as water conservation and soil improvement methods are more important than in depth analysis of micro variables in one method.
Kangas, Jyrki (1992, 1993) Kolli et al., (1993) Jankowski & Richard (1994)	Concerned with resource optimization. Kangas also describes support to the performance of other reforestation activities.	In developing countries, support for the effective performance of tree growing tasks is more important than resource optimization per se.

c) most of the systems are concerned with bio-physical variables of the site ignoring critical social elements that affect reforestation, and

d) most importantly, most of the systems were not developed with the social and economic needs of developing countries in mind.

PHASE II

CHAPTER 5

5.1 Reforestation As a Decision Making Process

Reforestation involves interrelated decisions that are reached sequentially (Kangas, 1992) following general procedures and principles (Kamweti, 1982; Glesinger, 1963). Reforestation decision areas according to Raintree (1991) and Kangas (1992) include: organization and management under which trees will be grown, selection of trees, selection of location and spatial arrangement in which trees are grown, and determining site preparation methods that are applied on a site. That means, having collected required site data, a reforestation project manager would have to decide, among others; who will manage the reforestation plantation, what type of plantations will be established, on which site niche, what type of trees will be planted and how the site should be prepared and protected.

Effective implementation of these operations requires that large and complex social, economic and ecological data structures be compiled and analyzed. Their complexity and volume is managed with a clear separation of phases and activities and well defined objectives and constraints.

5.2 The Reforestation Process

Reforestation involves the accomplishment of a pre-defined set of activities in a sequential manner (Khan, 1987; Kamweti, 1982; Ffolliot & Thames, 1983). The process can be divided into seven major phases:

- 5.2.1 Site survey and delineation of site niche boundaries,
- 5.2.2 Determination of the objectives (needs) and constraints of the reforestation project,
- 5.2.3 Determination of plantation types that will be established on the site niches,
- 5.2.4 Determination of the plantation management appropriate for the site,
- 5.2.5 Selection of strategy for mobilizing people,
- 5.2.6 Performance of tree growing operations:
 - Selection of tree species
 - Seed management
 - Nursery management
 - Site preparation
 - Planting
 - Plant protection, and
- 5.2.7 General assessment of site constraints and plan evaluation.

In Phase one, a site survey is conducted and the site parcelled out into niches whose ecological and socio-economic data are collected. In phase two, the purposes and constraints of the project are determined. In phase three, the plantation types which fulfil the needs of each site niche are identified. In phase four, the party who will be responsible for managing the plantation(s) is determined. In phase five strategies of mobilizing the people are designed. In phase six, tree growing operations, i.e., activities which deal with

selecting, planting and tending of the trees are performed. Lastly, a general assessment of the constraints of the site are made to assess the project's chances of the project's success. Each of the phases are described in detail next.

5.2.1 Reforestation Site Survey and the Delineation of Site into Niches

A site survey is conducted to collect reforestation site data. The conditions that a reforestation site exhibits can be divided into *global* (*regional*) or *niche* (*local*) characteristics. While global characteristics pertain to the total site (e.g., temperature and rainfall) niche characteristics refer to a particular site within the total area (e.g., land ownership, land usage, severity of run-off and soil type). Therefore, for effective data collection and planning, besides the total site area determination, the compartments of the site which exhibit similar characteristics have to be parcelled out (see table 10).

Table 10: Possible reforestation site niches

POSSIBLE SITE NICHES
River bank
Road side
Farm
Lake shore
Gully
Mountain side
Sand dune
Vicinity of water hole
Settlement
Railway side
Swamp
Grazing land

Both global and niche conditions can be divided into two sub-conditions: (1) *ecological* and (2) *socio-economic*. Each of these exhibits *needs* and *constraints*. While needs are the socio-economic and conservation requirements; constraints are climatic, physical and socio-economic elements that constrain the reforestation project.

Generally, needs are revealed through their symptoms. For example, a survey may reveal some or all of the following site symptoms (table 11: partly adapted from Bohlin, 1984):

Socio-economic symptoms	Ecological symptoms
Scarcity of:	
Firewood	Barren landscape
Animal feed	Erosion(gullies,land
Construction material	slides,flooding)
Game	Drifting sand
Money	Infertile(alkaline) soils

Table 11: Examples of Socio-economic and ecological symptoms

Several authors (Bonlin, 1984; Khan, 1987; Weber and Stoney, 1986; FAO, 1978) have discussed the data elements that have to be collected through a site survey. Some data elements extracted from Khan (1987) and the FAO (1978) are presented in table 12.

Table 12: Data to be compiled through a site survey

Global Site Conditions	Niche Specific Conditions
Ecological:	
Climate: rainfall temperature	Existing vegetation: trees shrubs grass
Geo-physical:	
latitude longitude General topography: altitude gradient ridges streams roads water holes lakes	Soil characteristics: depth structure fertility erosion: wind & water pH
Socio-Economic:	
Economic (needs and structures): timber firewood charcoal fruits fodder poles medicine fiber roads telecommunication lines Socio-cultural: scenery cultural attitudes institutions	human settlements farms boundaries of sites distance from nearest villages distance from water source mobilization strategies technological and other means
Labor: quantity seasonality skill	

Source: Khan, 1987; FAO, 1978

5.2.2 Determination of the Purposes of the Reforestation Project

A reforestation project's objectives are determined from the global and niche needs. The needs are evaluated to determine their importance to become project objectives.

Since site needs are many and varied, it is unrealistic to try to meet all of them in one reforestation project. It is desirable therefore, to limit the objectives to those needs that would bring the most benefit to the site. A multiple criteria preferential method which supports the performance of this task will be discussed in chapter 7.

5.2.3 Determination of the Plantation Types that Will Be Established on the Site Niches

Project objectives naturally lead to the plantation type(s) that should be established to meet the objectives. A plantation type is a group of trees that is established to serve a specific purpose(s) or to meet a specific need(s) of a site niche (see Raintree, 1991). Depending on niche similarity or difference, the group of trees may be limited to one or may span over several site niches. Table 13 presents a list of plantation types and their possible purposes.

Table 13: Plantation Types

A. Dispersed trees in grazing land: prevent erosion, enhance scenery, conserve wildlife.	H. Trees on farm boundaries: Prevent erosion, Demarcate boundary, Protect crops, Source of fodder and firewood.
B. Home garden: Fruits for humans, Animal feed.	I. Living fences: Protect area from animals.
C. Energy woodlot: Firewood, Charcoal.	J. Windbreaks: Prevent winderosion, Protect crops, Protect settlements.
D. Fodder Bank: Animal feed.	K. Trees on river banks: Prevent gullying.
E. Trees on Contour Strips: Prevent run-off.	L. Trees on lake shores: Prevent erosion, Shade for animals.
F. Shelter Belts: Prevent wind erosion over a wide area.	M. Trees along highways: Enhance scenery, Shade for travellers.
G. Trees near water holes: Shade for animals & humans, Prevent run-off, Prevent wind erosion.	

Source: Raintree, 1991

The needs of the site are evaluated against the type of plantation(s) to select a plantation type(s) for each niche. For example, a global feed deficiency and run-off erosion on a farm boundary may necessitate the establishment of a bush fodder bank on the edge of the farm. A rule-based approach of performing this activity will be presented in chapter 7.

5.2.4 Determination of Plantation Management

Plantation management, as already stated, refers to the party who will be responsible to plant and take care of the trees. Accordingly, the task in this phase is the evaluation of relevant site characteristics to determine who the most eligible party to assume this responsibility is; which implies that this party is the beneficiary of the project.

It is mainly the socio-economic elements that determine the eligibility of a given plantation management type. Variables such as ownership, security and length of ownership, capital availability etc., determine the decision of which plantation management type to adopt. Table 14 provides the plantation management options that can be selected for different site niches. A rule-based approach that recommends a plantation management type(s) for various site niches will be discussed in chapter 7.

Table 14: Plantation management types

Management of Tree and Land Resources	Control/Ownership of land		
	Communal	Private 1	Communal 2 State 3
	Private	4	5 6
Social Forestry Management Strategy: Communal, Farm forestry (private).		Characteristics 1. Tree growing on private lands by community institutions. 2. Communal tree growing on community lands. 3. Public land allocated for communal and community based forestry projects. 4. Privately managed tree planting 5. Privately-managed tree growing on communal or community lands. 6. Public land allocation schemes for private tree growing.	

Source: FAO, 1985

5.2.5 Mobilizing the People

Once the party that will be responsible for the plantation is known, how each party can be mobilized to perform tree growing operations will be determined. The major prerequisites for effective mobilization decisions are means, i.e., technology, resources and institutions and motivation (Ahlbäck, 1995). Ahlbäck suggests the following mobilization approach which leads to action:

1. ENCOURAGEMENT
 - 1.1 education (benefits of tree planting)
 - 1.2 removing uncertainty (access to planted trees and fair distribution of benefits)
 - 1.3 incentives (future and other benefits)
2. COERCION
 - 2.1 compulsory tree planting (how many trees to plant)
 - 2.2 right to plant trees
3. TRUST
 - 3.1 freedom of what, where and how to plant
 - 3.2 self-reliance

4. MEANS

4.1 technology

4.2 resources

4.3 institutions (village and other authority)

The need and form in which each of these factors will be delivered is evaluated taking local conditions into consideration. A rule based approach of how these decisions will be reached is explained in section 7.

5.2.6 Performance of tree growing operations

As was indicated earlier, this phase comprises six steps. The proposal however is limited to; tree species selection, site preparation and plant protection. Further, since tree species selection is a topic that has been discussed exhaustively (see Hall et al., 1972; Kamweti, 1982; Khan, 1987; Booth, 1991; Marathe et al., 1991; Carlowitz et al., 1993; Webb et al., 1984) its treatment will be very brief.

Tree Species Selection

In reforestation, the decision of which trees to plant is of critical relevance. Many reforestation projects are believed to have failed because of inappropriate choice of trees (Anderson, 1984; Goudie, 1990; Mnzava, 1982).

Effective choice of trees is based on their "utility" and "adaptability" to environmental conditions (Kamweti, 1982). To ensure adaptability, preference can be given to indigenous species existing in the locality or to those which have proved successful under similar ecological and socio-economic conditions. Other species, imported from regions with different climatic conditions, should be subjected to experimental planting before mass planting is undertaken.

If the tree species to be planted are not already known, one of computerized tree data bases (e.g., Marathe et al., 1991; Carlowitz et al., 1993; Webb et al., 1984) can be consulted. These can display trees for a variety of ecological and socio-economic conditions which a decision maker can include in the data base query string. How a tree data base will be implemented in the SFRP-DSS, will be discussed in chapter 7.

Site Preparation

Site preparation can be viewed as an activity which is undertaken to improve the soil conditions of a site which can affect the growth of a plant negatively. Planting on unprepared lands would mean "asking for very costly losses" (Kamweti, 1982). In arid lands, land preparation is particularly critical for water conservation purposes.

Site Preparation Purposes

Site preparation is undertaken for the following purposes:

- a. Remove all competing vegetation from the site (FAO, 1974; Hall et al., 1972; Kamweti, 1982). The objective of clearing the vegetation is to ensure that young trees do not have competition for moisture, nutrients and shade from other plants.
- b. Create conditions which will enable the soil to catch as much of the rainfall as possible (FAO, 1974; Hall et al., 1972; Kamweti, 1982). Various techniques of soil preparation (e.g., cultivating, ridging, terracing) help conserve moisture and improve the soil structure. These also provide good rooting conditions for the trees and as large a volume of rootable soil as possible.
- c. Leave conditions where mechanized tending operations can be carried out in the establishment stage after planting (FAO, 1972; Kamweti, 1982). This usually requires removal of all stumps.
- d. Create conditions where the danger of fire is eliminated or at least minimized (FAO, 1974; Kamweti, 1982).

The above objectives stipulate that the following factors be considered in selecting a soil preparation method:

- a. Vegetation on the soil- to determine the extent to which competing vegetation should be cleared,
- b. Hardness of top and sub-soil- to determine the extent to which cultivation is needed,
- c. Mineral content of the soil- to determine whether to apply or not to apply fertilizer,
- d. Moisture content of the soil- to determine whether a water harvesting type of soil preparation technique is necessary,
- e. Terrain (sloping or gentle)- to determine whether to use run-off control techniques (e.g., ridging, terracing or trenching),
- f. Size of plantation- to determine whether to use manual or mechanical site preparation techniques,
- g. Harmful agents on the site- to determine the use of site preparation as a protective measure.

Site Preparation Methods

Site preparation methods are the techniques applied on a site to achieve the site preparation objective or objectives that have been cited above. A site preparation method can be used singly or in combination with other methods. Seven site preparation methods can be identified.

a. Vegetation clearance: is a method of site preparation in which existing vegetation is felled and any stumps removed.

The method ensures that young trees do not have competition for soil moisture, nutrients and shade from other plants. In arid lands, the existing vegetation is usually sparse and competition not serious, but whenever there is a dense grass this should be removed for one to several feet from an individual planting spot some two to six months prior to planting. Careful evaluation of the advantages and disadvantages of clearing existing vegetation is important before deciding to apply this method.

b. Ploughing (harrowing): is a method used to loosen up the soil. In cases where the soil is strong or where an impervious pan is present, deep ripping may be essential for satisfactory tree growth.

c. Pitting: is a method of digging holes in which to plant the trees. In arid lands, Kamweti (1982) recommends that the dug out soil be returned to the hole to avoid desiccation of the walls of the hole. The soil can be removed just before planting.

d. Trenching and Terracing: are techniques used in a hilly country along the contours of the slope. Trenches and terraces have the triple function of: (i) catching run-off of rainfall, (ii) checking erosion, and (iii) providing favorable conditions for planting and sowing. This method is suitable for moderate to steep slopes.

e. Ridging: is a method suitable for flat or gently sloping ground. In this method, ridges are built at intervals by hoeing and the main ridges aligned along the contours and joined by smaller ridges at right angles creating a series of shallow basins bounded by ridges which hold the rain and prevent erosion.

f. Fire: is a technique which involves the cutting and burning of the vegetation on the site. The advantages of the method are: (i) the burn kills off weed growth, and (ii) the ash provides a useful fertilizer for the plants.

g. Fertilizer application: is a method applied where there is mineral deficiency in the soil. The availability or unavailability of minerals such as nitrogen, phosphorous, potassium etc. in the soil should be ascertained before a decision is made to add fertilizers.

Plant Protection

As stated earlier, the failure to protect young trees from adverse environmental and social elements stems from the failure to formulate and implement an adequate reforestation plan (Kamweti, 1982). The same author stresses that given the cost incurred in planting trees, some extra cost is justifiable for protecting those trees (Kamweti, 1982).

Table 15 provides a partial list of the elements from which trees have to be protected.

Table 15: Hazardous site elements

Environmental	Social
Direct sun Desiccating winds Floods Diseases Insects (pests) Other plants (e.g., weeds)	Humans Animals

Source: Kamweti, 1982; Goor & Barney, 1976.

A number of protection measures which are applied based on the presence (or absence) of the elements cited above, are provided in table 16.

Table 16: Tree protection methods

METHODS TO PROTECT YOUNG TREES
<ol style="list-style-type: none"> 1. Watering: to be used when rainfall fails and when a planting season might be lost otherwise. 2. Fencing and Spraying seedlings with repellents: to protect seedlings from damage by animals. 3. Cultivation and weeding: to minimize mortality from competition. Best applied about six to eight weeks after planting. 4. Chemical and phytosanitary measures against insects: phytosanitary involves the inspection and destruction of nearby vegetation that harbors harmful insects. Chemical measures include the spraying of plants with insecticide. 5. Supervision: used to protect young trees from animals and humans. 6. Shading: used to protect young trees from desiccating direct sunlight.

5.2.7 Project Success Assessment

The obstacles that a reforestation program faces, as was explained in section 3.3, are complex and varied. They are also intimately related to the prevailing temporal conditions

aesthetic, cultural, institutional) and economic (e.g., food, feed, capital, infrastructure) conditions of the area. Further decompositions break down the site to the desired level of detail (fig. 6).

This representation is generic and does not refer to any particular site. Assigning values to the bottom level variables of the hierarchy (e.g., from a questionnaire designed for data collection), however, constitutes a specific site representation.

These data are used for various subsequent planning operations. Some are used to select the tree(s) from the tree data base. For example, latitude, elevation, rainfall, temperature, type of soil, firewood, fodder and fruits are site constraints and needs which are employed to query a tree data base to select a suitable tree. Some other characteristics become site needs automatically, enabling objective determination. For example, firewood scarcity, green manure deficiency, animal feed shortage, fruits for human consumption and run-off erosion translate into respective socio-economic or ecological needs of a niche. Niche characteristics such as presence of pests and animals, site

CHAPTER 6

6.1 Effective Computerized Decision Support for Reforestation Planning in Developing Countries

The preceding chapters demonstrated that reforestation in developing countries has exhibited remarkable failures due to lack of methodical site evaluation and the ineffective application of tree growing techniques and principles. These, it was concluded, mainly resulted from the failure to pre-plan the task adequately. Meanwhile, it was found that no systems exist to support plan the task effectively.

An effective DSS, as was suggested earlier, aids management decision making by: (see Vlek et al., 1993): (a) supplying relevant knowledge (data) to the decision maker, (b) structuring the decision problem such that choice alternatives become visible, and (c) evaluating alternatives for their relative merit. Similarly, an RDSS should support the decision maker by supplying relevant site knowledge, structuring reforestation knowledge and providing feasible action-plan alternatives.

To build an RDSS which is compatible to the social and economic conditions of developing countries, at least three tasks need to be specified clearly: (a) the activities to be

supported (i.e., problems to be addressed), (b) nature of the hardware required, and (c) type of software to be used.

a. Operations to be Supported

An RDSS, as was stated, should first support the decision maker to structure reforestation knowledge. This can be done following the natural reforestation processes through which the system guides the planner providing feasible alternatives from which selections are made. To make an allowance for obstacles which have not been captured by the plan, the system should then aid the planner to perform a systematic assessment of all possible site problems. The planner then devises alternative strategies to overcome the obstacles.

Table 17 provides the steps through which the DSS guides the planner and lists reforestation obstacles with which the planner diagnoses the reforestation site. The specific nature of the support is explained in chapter 7.

Table 17: Problems to be diagnosed and reforestation steps to be supported by SFRP.

Provides support to:
<p>1. Methodical Guidance through reforestation process:</p> <ol style="list-style-type: none"> 1.determination of objectives 2.determination of plantation types 3.determination of plantation management 4.tree selection, 5.site preparation, and 6.seedling protection. <p>2. Diagnose Problems:</p> <p>land ownership insecurity, cultural concepts of trees as free goods, competition between reforestation and agriculture for labor and land, competition between reforestation and livestock for land, failure to elicit needs of villagers, marginal contribution of reforestation projects to participants needs, loss of private land to communal use, scarcity of water (abnormal rainfall), poor soils, biotic agents, financial problems (delays in budget release and sudden budget cuts), excessive costs, unequal distribution of benefits, inadequate supervision, failure to determine:</p> <ul style="list-style-type: none"> -what seeds will be needed, -how much labor will be required, -what transport are available and will be ready, -time table of different activities to be performed, <p>concern with targets of trees planted than trees that survive, inadequate protection measures from animals, fire, humans and weeds, failure to assess environment in which trees are grown.</p>

b. Hardware Requirements

To function properly, computer support systems require technological and economic infrastructures such as telecommunication lines, energy and other supplies. Further,

since many of the hardware components in a computerized DSS are delicate, particularly when exposed to environmental extremes, repairs are inevitable (Dow et al., 1986). Meanwhile, developing countries do not have much foreign currency and apply strict controls on how computers are imported (Gotlieb, 1982). As a result, the choice of brands is limited, spare parts are unavailable and their delivery can be time consuming and unreliable (Dow et al., 1986).

However, new trends in computer technology coupled with sound management, make the adoption of computer support systems rather promising:

"...microcomputers are becoming less and less expensive, with the 'throw away' \$100 computer not too far off. Portable, battery operated microcomputers could be used in field operations and remote communications; some microcomputers have been shown to be durable and efficient in hot, humid, and dusty rural environments. Their ruggedness, reliability, and range of capabilities make them excellent tools for information handling in the field, in small towns, and even in isolated villages; used as a field tool, the microcomputer would make possible data entry and checking at the survey site" (Schware and Trembor, 1987).

Since the physical environment in most developing countries is severe (hot, dusty, lacking in computer supplies and energy, lacking in transportation facilities, etc.), the hardware component of an RDSS should be durable, portable, dust resistant, and able to operate with minimum supplies and energy.

c) Software Requirements

Developing countries are characterized by a relatively thin layer of expertise at the top, a huge unskilled labor force at the bottom, and a very thin layer of technicians in the middle. Moreover, many of the everyday problems and solutions of developing countries have not assumed the degree of complexity in the developed ones (Mann and Ruth, 1992). Therefore, there are substantial number of areas where simple software tools can make a more useful contribution than sophisticated ones (Mann and Ruth, 1992).

The potential of intelligent systems which capture relatively simple levels of expertise may be particularly useful. To some extent, they can substitute the missing middle level technician, allowing less well-trained persons to perform technical tasks assisted by intelligent computer support (Mann and Ruth, 1992).

Similarly, to properly function in developing countries, an RDSS should: (i) be simple enough to be operated by less-skilled personnel, (ii) augment the low level of expertise in the countries, and (iii) deal with the common everyday, though critical, problems facing those countries.

Table 18 presents a summary of the desirable hardware and software features the RDSS should possess.

Table 18. Proposed hardware and software features of RDSS

Nature of Problems in Developing Countries	Desired Hardware Characteristics	Desired Software Characteristics
1. low level skilled labor	simplicity of use and maintenance	captures simple expert knowledge, easy to operate and upgrade
2. shortage of foreign currency	cheap, reliable and well planned access to suppliers of spare parts and supplies	can be upgraded locally
3. power outages, dust, heat and humidity	use of battery operated computers, alternative sources of energy in case of power black/brown outs, and a plan to secure a well ventilated and dust proof place.	does not make large demands on hardware
4. general low level development	inexpensive, durable	comprehensive support as opposed to narrowly focused

CHAPTER 7

7.1 Representation of Reforestation Planning Process

The representation of the reforestation process defines the various agents involved in the task and how they are inter-related. It outlines sites, trees, methods, activities, data and the steps involved to plan the process. In this section, first, representation of the site in the form of hierarchical data structure is provided; second, detailed representations for each of the phases are outlined, finally, an overall representation (model) of the planning process is presented.

7.2 Detailed Representation of Reforestation Planning Phases

7.2.1 Representation of Site

Site data can be captured in a hierarchical structure. A hierarchical data structure is a multi-level, tree structured, decomposition of the characteristics of a site. The data are first broken down into regional and niche characteristics. These are further broken down into ecological and socio-economic attributes. These attributes are in turn sub-divided into needs and constraints. Ecological needs/constraints are further decomposed employing: (a) bio-climatic, (b) physical, and (c) soil characteristics. Socio-economic needs/constraints are represented using the social (e.g., demographic,

Figure 6 Partial representation of reforestation site.

aesthetic, cultural, institutional) and economic (e.g., food, feed, capital, infrastructure) conditions of the area. Further decompositions break down the site to the desired level of detail (fig. 6).

This representation is generic and does not refer to any particular site. Assigning values to the bottom level variables of the hierarchy (e.g., from a questionnaire designed for data collection), however, constitutes a specific site representation.

These data are used for various subsequent planning operations. Some are used to select the tree(s) from the tree data base. For example, latitude, elevation, rainfall, temperature, type of soil, firewood, fodder and fruits are site constraints and needs which are employed to query a tree data base to select a suitable tree. Some other characteristics become site needs automatically, enabling objective determination. For example, firewood scarcity, green manure deficiency, animal feed shortage, fruits for human consumption and run-off erosion translate into respective socio-economic or ecological needs of a niche. Niche characteristics such as presence of pests and animals, site

landscape and site fertility determine selection of tree protection and site preparation techniques.

The site data structure can be referenced to a map of the site. A map featuring global and niche characteristics such as water sources (e.g., water holes, streams, lakes), landscape relief (e.g., elevation, inclination) infrastructure (e.g., roads, telecommunication lines), land use (e.g., farms, pasture, pathways) is a user friendly representation which displays the prominent features of the site.

7.2.2 Representation of Objective Determination Process

Once all relevant data values have been put in the site data structure, the next task is to identify the needs which require prompt attention. One approach is to employ a multiple criteria decision method (MCDM) which helps the articulation of the decision maker's preferences through a prioritized list of needs. The needs which rank high in the list would become the objectives towards which project efforts would be focused. Fig. 7 illustrates the objective determination process in a flowchart form.

7.2.3 Representation of the Selection of Plantation Types

The representation of the plantation-types-selection process:

(a) identifies the site variables which determine the appropriate plantation for a site, and (b) outlines the procedure through which the process is accomplished.

Both global and niche variables (needs) determine the right plantation for a niche (fig. 8). These needs are matched, (e.g., through an IF-THEN rule base), against the ecological and/or socio-economic needs the plantation is expected to meet. The plantation types which are the most promising are then recommended to the planner. The planner can then select one or more of the recommended options for a niche(s), based on his/her intimate site knowledge.

Figure 7 Reforestation objective determination process

7.2.4 Representation of Plantation Management Selection

Given relevant regional and niche characteristics, the procedure followed in selecting plantation types can be duplicated for the selection of a plantation management type for a niche. In this section: (i) characteristics which determine the selection of a plantation management are identified, and (ii) the procedure which is followed to reach the decision is outlined.

Site characteristics that determine the selection of a plantation management are related to the use, ownership and the gain of the benefits of the plantation on the site niche (Fig. 9). These are investigated and the plantation management types which are likely to be feasible for the niche recommended to the decision maker. The decision maker then selects one or more of the recommended options based on his/her intimate knowledge of the site.

Figure 8 Representation of plantation types selection process

Figure 9 Partial representation of plantation management authority selection process

7.2.5 Representation of People Mobilization Strategy

Representation of mobilization strategies deals with the identification and structuring of the site conditions (data) that influence the adoption of particular *people mobilization strategy*. The state of the site regarding a group of these variables will determine the type of the strategy to be recommended by the reforestation DSS.

The data are chiefly socio-economic in nature reflecting community awareness, attitudes, leadership, access to open forests, availability of required resources etc., regarding reforestation (fig. 10). An IF-THEN *mobilization strategies* rule base will be created and linked to the values of these variables in a database file. The system will then recommend the feasible mobilization strategies to the decision maker who will decide which one(s) to adopt given his intimate knowledge of the site.

7.2.6 Representation of Tree Species Selection

The representation of tree species selection deals with a tree data base and the steps followed in formulating a query into these data base. However, this proposal does not deal with the construction of tree data bases as such. Moreover, trees can

be put into the system directly if the planner decides to do so.

Figure 10 Partial representation of mobilization strategy selection process

Even though how queries are formulated will vary from one data base to another, generally, the process of selecting the right tree can be performed in three steps (see fig. 11):

a. Determination of ecological and socio-economic requirements of the site.

The first step of the tree selection process is the identification of the ecological and socio-economic requirements of the site. These data should have been secured at the reforestation purpose determination stage. Generally, the requirements fall within: (i, ecological constraints in which the tree will grow, e.g., temperature, rainfall, soil type, etc., (ii) ecological benefits, e.g., nitrogen fixation, erosion control, etc., and (iii) socio-economic benefits to the community, e.g., fodder, food, fuel, shade, poles etc.

b. Querying the tree data base

A query is then formulated using the information described above. For example, the decision maker may enter the constraints and needs exhibited in table 19 and obtain candidate trees from which he/she can make a selection.

Table 19: Tree selection criteria

Ecological constraints and benefits:	Socio-economic benefits:
Constraints: Rainfall: 600-800 mm Altitude: > 1500 meters Soil: Sandy Benefits: Nitrogen fixation Erosion control	Shade Fodder Fuel Fruit

Figure 11 Tree species selection and mix determination process

c. Select tree for site trial

The tree which passes the test of the constraints and benefits would then be eligible for site trial before mass planting can be effected.

d. Determine tree mix

The determination of the tree to be planted does not resolve the problem of how many trees to plant and in what ratio. To compute this, three data items: the importance of the tree in meeting local needs, the area to be planted and the spacing of the trees are required. Tree importance is obtained from the MCDM that has been described in the objective determination section; area is obtained from the site map and espacement from the tree data base.

For example, given that importance for trees X and Y is .2 and .3 respectively and the area to be planted is 2,400 square meters with espacement 4x4 for both trees, the number of trees to be planted would be 150 in a ratio of 60 to 90 as shown in table 19.

Table 20: Tree mix determination

Trees	Importance	Area to be planted	Espacement	Number of trees to be planted	Mix of trees to be planted
X	.2	2,400 sq. m.	4X4	$2,400/16=150$	$150 \times 2/5 = 60$
Y	.3				$150 \times 3/5 = 90$

7.2.7 Representation of Site Preparation Methods Selection

The representation of site preparation methods selection process deals with the methods available for site preparation and the variables (factors) that determine their application. Fig. 10 breaks down the factors that affect site preparation in a hierarchy. Assigning values to the variables enables the determination of site preparation methods to be applied on the site.

Niche values of these variables are linked to an IF-THEN rule-base and feasible methods suggested to the planner. The planner then selects one or more of the recommended methods based on his/her intimate knowledge of the site.

7.2.8 Representation of Plant Protection Methods Selection

Plant protection representation: a) identifies the site elements that are hazardous to young plants b) presents the

protection measures that are available, and c) provides recommendations of protection measures based on prevailing site hazards. Fig. 13 presents, in a hierarchical structure, the possible hazards on a site and available protection measures³.

Figure 12 Partial representation of reforestation site preparation process

³ The reforestation case in the thesis demonstrates how this is performed.

Figure 13 Partial representation of plant protection method selection

A tree protection methods rule base which incorporates the global and niche hazards would present feasible protection measures to the decision maker. The decision maker, based on his/her insight would then, select one or more of the supplied options.

7.2.9 General Evaluation of Reforestation Plan

The obstacles that have hindered the success of reforestation projects have been presented in section 3.3 and elaborated in chapter six. It has also been pointed out that a DSS may not be able to capture and formulate a plan for all possible obstacles. This phase attempts to capture these through a direct question/reply interface with the decision maker; to either plan alternate additional measures or to revise the plan that has been formulated.

Each of the obstacles is presented to the planner who indicates, on a five point weight(w) scale, their critical nature to the success of the project and assigns values(x) (e.g., favorable (1), unfavorable (0)) to their conditions on the site. The weights and values are then multiplied and their sum converted into a percentage which is a general assessment figure relative to zero and the expected highest score⁴. For example, if;

$$S = \sum w_i x_i$$

h = highest possible score

P = percentage of success favorableness

then, $P = S \times 100 / h$

⁴ The reforestation case demonstrate how this is performed.

Based on the assessment, the planner decides either to proceed with the current plan, integrate alternative plans into it or discard the old plan and formulate a new one.

7.3 General Representation of Reforestation Planning Process

The overall representation of the reforestation planning process within the scope of this thesis, can be illustrated by integrating all the agents and activities that have been explained thus far. Decision support tools and techniques that the planner may utilize are also presented.

As fig. 14 illustrates, six activities: determination of reforestation objectives, plantation types, plantation management, and the selection of: trees, site preparation and plant protection methods are performed utilizing decision support tools of GIS, MCDM, tree data base, and four rule bases in a sequential manner. Before producing the final output, the system, through a question/reply interface, captures and assesses the variables which have not been captured in the plan.

Figure 14 Design of KB-RDSS for planning reforestation projects in developing countries.

Phase III

Chapter 8

8.1 The Reforestation Planner: A Demonstration

This chapter provides a simplified version of the reforestation planning DSS that has been discussed so far. Since the aim is to demonstrate the feasibility of the tool, only a small number of the variables that affect **two steps**: the determination of **people mobilization strategy** (PMST) and the selection of **plant protection method** (PPMT) have been included in the database. Moreover, the final plan has been restricted to one, instead of to all site niches of the area.

The demonstration makes use of a reforestation site that was studied by Thapa and Weber (1994). Their study deals with the prospects of private forestry in an area near the town of Pokhara in Nepal. A summary of the reforestation needs and constraints of the area, as explicitly stated or implied by the authors, is given in Table 21.

Even though site data in the table depict what is discussed by Thapa and Weber (1994) accurately, two issues make the final plan of the demonstration not necessarily applicable to the area. First, the selection of the feasible options has not been made with an intimate knowledge of the area. Best results are expected when alternative choices are made with the intimate knowledge of the site, preferably with stakeholders

2 OF/DE 2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

taking an active part in the process. Second, only dummy strategies and trees have been put in place of the reforestation operations that have not been included in the demonstration.

Table 21: Site needs and constraints of Pokhara area.

Needs and Constraints of Study Area					
Economic		Ecological		Social	
Needs	Constraints	Needs	Constraints	Needs	Constraints
1.Fire-wood 2.Fodder	1. Employment -> low 2.Labor force -> seasonal low 3.Capital and tree planting equipment -> low 4.Seedlings -> not available	1.Run-off control 2.Green manure	1.Mountainous 2.28°17' to 28°19' North latitude to 83°51' East latitude 3.Elevation ->1,524-2134m 4.Long warm summers and short cold winters 5.Temperature -> lowest 8.7°C ->highest 20°C 6.Seasonal rainfall 4700mm ave. 7.Hailstorms ->severe 8.Soil -> non fertile	1. Boundary delineation	1.Marginal size land holdings (shortage of land) 2.Open access forests 3.Land use: agriculture (51%), forest (40%), grazingland (10%). 4.Popular support to conservation and development initiatives -> good 5.Grazing animals ->present 6.Tree planting practices, attitudes and skills -> low 7.Uncertain woodlot holding laws 8.Some tenant land holdings 9.Land ownership -> private (farm areas)

Source: Thapa & Weber, 1994

The demonstration is designed as a **Windows Group** in which icons in numerical sequence represent modules in the order in which they should be called to action (Fig. 15).

The modular design has been chiefly dictated by the loose coupling of independently functioning software applications. For example, since GIS capabilities in Visual Basic were not at hand during the development period, MapMaker had to be the first independent module for survey and site map preparation. Similarly, since Expert Choice and VP-Expert could not be linked to and called from Visual Basic, they had to be started from their own independent interfaces. With further developments, it is expected that Visual Basic-GIS routines will replace MapMaker to support the GIS functions that are required by the DSS. The construction and performance of each module are described next.

Fig. 15 Reforestation Planner as a windows group

1. Site Survey and Map Preparation

Since the demonstration is based on a previous study, **survey of the site and the preparation of the manual map** were already

accomplished by the study. This is expected to be the most time consuming part of the planning process. It is recommended that FAO's (1989), Community Forestry: Rapid Appraisal, and MapMaker's surveying tools (or their equivalent) be used for this operation. As stated, with emerging Visual Basic-GIS capabilities, the preparation of the site map and its integration to the database is expected to be performed from Visual Basic programmatically.

In the demonstration, the manual map was enlarged 200% and scanned as a one bit uncompressed TIFF file using the OmniPage graphics application. It was then processed to remove any objects in the map leaving only external boundaries. The file was then imported into MapMaker and calibrated. This calibrated map constituted the base map. Two layers: site niches and rivers were then added onto the map (Fig. 16). Based on a broad land use categorization of the area (Thapa & Weber, 1994), the site niches are: two forest areas, a village, a farmland area, and a grazingland area.

The site niches were linked to a database using MapMaker's data-file generation capability. Even though map-to-database integration is supposed to be possible, it proved to be time consuming and only part of the data could be displayed successfully. The construction of the database is described next.

Fig. 16. Map of area surrounding Maramche village, Nepal
(modified from Thapa & Weber, 1994).

2. Site Data Entry

The database, which includes the economic, social, and ecological needs and constraints of the site was developed in dBase. Choice of the database was dictated by its availability and compatibility with Visual Basic, MapMaker and VP-Expert. Even though MicroSoft Access was more compatible with Visual Basic and could be read by MapMaker, it had to be abandoned in favor of dBase because of its inaccessibility from VP-Expert.

In order to simplify data access, only two tables: a niche data-table and an objectives table were created. Site niches constituted the records in both tables while needs/constraints and strategies/trees formed the fields within records. The database tables are expected to be divided into more homogenous, smaller tables with the increase in the size and complexity of the DSS.

The user interfaces the database through a Visual Basic data entry module which provides drop down menus for the data options to be entered. Fig. 17 illustrates the interface through which site needs are selected and entered into their respective database fields. A similar interface exists for site constraints.

Fig. 17 Interface for entering site niche needs

Site data obtained from table 21 were entered into the database through these two interfaces. Besides facilitating data entry, the module incorporates a routine which extracts the needs of the site and constructs an objectives hierarchy (Fig. 18) similar to the one to be developed in module N°3. This can be printed to facilitate the objectives' entry process.

The intermediate printing and entering of objectives in modules two and three, is indicative of the non-portability of files between Visual Basic and Expert Choice. As mentioned earlier, a Visual Basic routine which performs the pairwise

comparison by Expert Choice can be provided with the further developments of the DSS unless the user specifically opts for Expert Choice.

Fig. 18. Hierarchy of reforestation objectives

3. Reforestation Objectives Determination

The potential objectives obtained from the previous module are then copied into an **Expert Choice** objectives hierarchy created in module N°3 for pairwise comparison.

In the example, pairwise comparison of the objectives was performed based on their importance to meet the needs of the

area as explained in section 4.1. The synthesis of the comparison then produced a prioritized list of objectives as shown in Fig. 19.

Based on this list, two activities are performed: (a) the number of the objectives can be reduced based on their weight. Thus, the objective of nitrogen fixation was dropped from further consideration given its marginal weight as compared to other objectives. (b) objectives are assigned to each site niche for which a plan is to be designed.

4. Entering Selected Objectives into site Niche

Module N°4 is used to enter the objectives in each site niche. It provides an interface with drop down menus for all possible economic, ecological and social objectives from which the decision maker(s) can make a selection. The selection, however, is limited to those objectives determined in step N°3. The module interfaces the user with the objectives database in much the same way as has been explained for the site needs/constraints interface.

In the example, green manure, fodder production, boundary delineation, and firewood production were entered into the objectives database for site niche **FarmLand**. These objectives would not be a random guess given the shortage of firewood, depletion of soil fertilizers, existence of grazing animals

and shortage of land resources in the area (Thapa & Weber, 1994).

Fig. 19 Expert Choice pairwise comparison results

Abbreviation	Definition
FRUITS	fruit production
FODDER	fodder production
BOUNDARY	Boundary delineation
WATEROSC	water erosion control
FIREWOOD	firewood production
SHADE	shade against direct sun
POLES	production of poles
GREENMAN	green manure
SCENERY	scenic beauty objective
NITRGEN	nitrogen fixation

For Trial Use Only

5. Consult Reforestation Expert

After all site needs, constraints and objectives have been entered, module N°5, the reforestation consultant in **VP-Expert**, is activated to plan the remaining reforestation

operations. While, according to the reforestation model, a complete reforestation planning consultation would include strategies for plantation types (PTYPEs), plantation management authority (PMGTA), people mobilization strategies (PMSTs), site preparation methods (SPMTs), and plant protection methods (PPMTs), the demonstration considers only PMSTs and PPMTs. Moreover, since a complete knowledge-base development for these two operations would require extensive literature search and expert discussion, only a limited number of the variables which affect the operations was considered.

Besides reforestation case studies that were analyzed, two foresters with developing country experience were consulted to suggest feasible PMSTs and PPMTs given site constraints. This constituted the sample knowledge-base which deals with a few number of variables that affect PMST and PPMT (Fig. 20).

The expert system searches the values of a site's constraints/needs and fires appropriate rules which recommend feasible strategies. From these, the demonstration allows the selection of **only one** strategy. The strategy is then entered into the database as a plan of action for the given operation. The options to be entered are not confined to the choices that are provided, however. The decision maker(s) can enter any other strategy that is deemed to be more appropriate.

Moreover, the knowledge-base can be expanded to include additional strategies.

Fig. 20 Sample VP-Expert code

```
!This file, REFPPRO.KBS will access data from a database
!called Maram.dbf and objdbase.dbf. The relevant field
!names are ID,IDO,PPRO1,PPRO2 and PPRO3.
  RUNTIME;
  ENDOFF;
ACTIONS
  DISPLAY" WELCOME TO THE REFORESTATION PLANNING CONSULTANT.
    CONSULTATION WILL SEND INFORMATION TO THE SCREEN
    AND PRINTER. MAKE SURE THAT YOUR PRINTER IS ON.
    Press ENTER to start consultation.~"

  DISPLAY" TASK 2:  DETERMINE PLANT PROTECTION METHODS FOR
    REFORESTATION SITE NICHE"
  MENU Constr,ALL,c:\dbsample\maram,id
  FIND Constr
  GET Constr=id,c:\dbsample\maram,ALL
  MENU Strat,ALL,c:\dbsample\objdbase,ido
  FIND Strat
  GET Strat=id,c:\dbsample\objdbase,ALL
  FIND Screen
  DISPLAY" Press ENTER to continue"
  GETCH Pause
  DISPLAY"Consultation finished. Please, press ENTER to exit EXPERT.~"
  CLS;
RULE 1
  IF  Grazing_an = Free
  THEN Screen = Yes
    DISPLAY"  SEARCHING FOR PRESENCE OF GRAZING ANIMALS HAZARD...."
    DISPLAY" Site Niche: {id}"
    DISPLAY" is an area where grazing animals are {Grazing_an}"
    DISPLAY" Given this constraint, you can consider one or more"
    DISPLAY" of the following methods to protect the plants:"
    DISPLAY"          (a) individual tree fencing"
    DISPLAY"          (b) supervision"
    RESET New_PPMT
    FIND New_PPMT
    PPMT1 = (New_PPMT)
    DISPLAY"{PPMT1} has been entered into {ido} plan"
    PUT c:\dbsample\objdbase
    Reset Screen
  ELSE
    DISPLAY"SEARCHING FOR PRESENCE OF GRAZING ANIMALS HAZARD...."
    DISPLAY"Grazing animals are not a hazard in {id}"
    DISPLAY"Press enter to continue"
    Getch Pause;
```

Figure 20 (cont.)

```
RULE 2
  IF Hail_Storm = Severe
  THEN Screen = Yes
    DISPLAY" SEARCHING FOR SEVERITY OF HAIL STORMS...."
    DISPLAY" Site Niche: {id}"
    DISPLAY" is an area where HAILSTORMS ARE {Hail_Storm}"
    DISPLAY" Given this constraint, you can consider one or more"
    DISPLAY" of the following methods to protect the plants:"
    DISPLAY"          (a) Erect Shelters"
    DISPLAY"          (b) Harden plants in sheltered nursery"
    RESET New_PPMT
    FIND New_PPMT
    PPMT2 = (New_PPMT)
    DISPLAY"{PPMT2} has been entered into {ido} plan"
    PUT c:\dbsample\objdbase
    Reset Screen
  ELSE
    DISPLAY"SEARCHING FOR SEVERITY OF HAIL STORMS..."
    DISPLAY"Hail Storms are {Hail_Storm} in {id}"
    DISPLAY"Press enter to continue"
    Getch Pause;
  ASK Constr: "SEARCHING FOR POTENTIAL SITE NICHE CONSTRAINTS.....
    Select the site niche for which you would like to do a search";
  ASK Strat: "To which site niche would you want to store your strategy?";
  ASK New_PPMT: "Enter protection method you select.";
```

As stated earlier, only **FarmLand** was selected for potential reforestation constraints with respect to PMST and PPMT. A consultation session was run for each operation. A sample consultation for land insecurity and open forest access constraints looked as illustrated in Fig. 21. Whereas landownership security was found not to be a disincentive, open forest access was deemed to be a constraint with feasible strategy options of environmental education and guarantee of adequate economic returns.

At this stage, with only three sample strategies, it appears that as more and more constraints are considered the

recommended strategies will also increase proportionately. This is expected to increase the volume of plan output for each reforestation operation unless a fewer strategies are found to address more and more constraints.

Fig. 21 expert system consultation session output

```
To which site niche plan would you want to store your strategy?
P FOREST1      P FARMLAND✓      P VILLAGE      P GRAZINGLAND      P FOREST2

SEARCHING FOR LANDOWNERSHIP SECURITY.....

FARMLAND land right is Secure...A FAVORABLE SITUATION

Press enter to continue
SEARCHING FOR FOREST ACCESS...
Forest access in the area is Open
Given this constraint you can consider one or
more of the following strategies to motivate the people to
plant trees: (a) Provide environmental education
              (b) Ensure adequate economic returns

Enter mobilization strategy you select.
  Provide env. education

Enter to select      ? for Unknown      /Q to quit
```

6. Evaluate and Finalize Plan

With the selection and entry of the chosen PMSTs and PPMTs, the plan is completed. The next task is to view the plan and to evaluate its success or favorableness potential. Module N°6 provides Visual Basic routines that enable the viewing and reviewing of the final plan and the site map (Fig.22).

Fig. 22: Final plan view and review module

The evaluation list is meant to show the nature of the evaluation issues to be considered. Therefore, a sample of only eight issues which can significantly impact the success of a reforestation project has been provided as shown in Fig. 23.

Fig. 23 Final Plan evaluation

An evaluation was conducted in light of site conditions as discussed by Thapa and Weber (1994) using the quantitative model that was discussed in section 7.2.9. The weights that were assigned to the site conditions and their computation results are shown in table 22.

Table 22 Reforestation success favorableness computation

Reforestation success factors	Importance	Favorableness	
Land ownership security	5	3	15
Land ownership length	4	3	12
Water supply	3	3	9
Community receptiveness	4	2	8
Land availability	5	1	5
Village conflict	4	2	8
Benefit size	4	2	8
Benefit allocation	4	3	12
			77/120=64%

The final plan for the OBJECTIVES, PMSTs and PPMTs was then obtained as in Fig. 23. According to the plan, the locals would prefer to plant trees for firewood, fodder and boundary delineation on their farmlands. The best incentives to mobilize the people to plant the trees would be the provision of free seedlings, environmental education and ensuring that the economic returns from the trees are satisfactory. The best protective measures would be individual tree fencing from grazing animals and hardening seedlings in the nursery from hailstorms.

Fig. 24 Final FarmLand reforestation plan

Site Niche Final Plan

P_FARMLAND **DataBase**

642

LandOwners

Firewood Production

Fodder Production

Boundary Delineation

XXXXXXXXXXXXXXXXXXXXX
 XXXXXXXXXXXXXXXXXXXXX
 XXXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXXX
 XXXXXXXXXXXXXXXXXXXXX
 XXXXXXXXXXXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXXX

PMST1: Provide free seedlings

PMST2: Provide env. education

PMST3: Ensure adequate returns

Individual tree fencing

Harden Seedlings in Nursery

Cancel

Review Final Plan

Print

CHAPTER 9

9.1 Conclusion

This thesis discussed and demonstrated that: (a) deforestation is a serious environmental threat to developing countries, (b) reforestation projects, particularly through social forestry, are the most favored and widely used measure to combat deforestation, and (c) reforestation projects have generally failed due to a lack of effective planning and implementation which stems from the failure to appraise local ecological and socio-economic variables systematically.

The paper then determined that reforestation is a sequential decision making activity which can be effectively planned through a knowledge-based decision support system. However, a review of the literature revealed that present decision support systems are at best narrowly focused systems which do not consider the needs and constraints in developing countries.

Based on this, the paper designed a knowledge-based DSS which addresses aspects of reforestation planning that are of particular relevance to developing countries. It then provided a general and detailed design of the DSS.

A prototype DSS which includes a GIS, a multiple criteria decision making tool, a database and a knowledge-base was also developed. The prototype was employed to produce a partial plan for a reforestation site in Nepal, taken from a study made by Thapa & Weber (1994).

At this preliminary stage, the following points can be raised regarding the benefits, training requirements, and further developments of the DSS.

Envisaged Benefits

It is expected that the employment of the tool will motivate project initiators and participants to think about their economic, social and ecological environment before undertaking reforestation projects. The structuring of reforestation knowledge into clear alternative strategies from which choices can be made is also expected to provide an incentive to project initiators to involve local participation which will lead to a better communication and understanding. The maps and databases developed for the purpose of reforestation are also expected to be an important repository of data for related operations.

Required Skills, Hardware and Software

The skills, hardware and software required to run the system will depend on its short term as well as long term future developments. At this stage, the minimum requirements to make the system operational include: (a) basic survey and map preparation skills, (b) computer literacy, particularly Windows experience, (c) a personal computer with approximately 200 megabytes hard drive and 8 megabytes random access memory and (d) software applications of dBase, Windows3.1, Expert Choice, MapMaker and VP-Expert.

Future Development Considerations

The immediate next task in the further development of the system is the incorporation of GIS and Expert Choice routines in Visual Basic, which are required by the system. The system does not need full fledged GIS and Expert Choice capabilities. Once this is completed, a modest tree database and preliminary knowledge-bases can be developed for all the reforestation operations suggested in the design. Since the decisions made at previous operations affect those of the ensuing ones, effective knowledge-bases can only be developed when all relevant operations are included in the system.

The system is then ready for field testing. Test locations in designated developing countries would be chosen and participants asked to use the system and to provide their feedback. This will lead to the refinement of the knowledge-bases, and other database, interface and program routines prior to the distribution of the system.

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