Bringing agroforestry technology to farmers in the Philippines: Identifying constraints to success using systems modelling

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Abstract

Bayesian Belief Network (BBN) modelling may be applied in rural extension in situations where program outputs are influenced by variables which are sequentially influenced by other variables. For a recently completed agroforestry extension program in Leyte the Philippines, BBN modelling of site factors, establishment practices and risk, predicted widely different program outputs for different levels of extension assistance and farmer inputs. In a situation where very little was known about how farmers would respond to offers of extension assistance, monitoring of the program over a period of three years revealed that extended extension assistance was crucial in determining the likely survival and growth of trees. Extended extension assistance was also important for the elimination of unsuitable sites and the use of appropriate establishment procedures. Where extension support was not available, farmers displayed a poor knowledge of the principles of tree growth, planting trees underneath complete canopies and adjacent to mature coconut palms even though they could have been expected to have extensive local knowledge of raising and growing plants. Approximately one third of planting sites were infertile and eroded and growth of newly planted trees on these sites was poor, often because site preparation and maintenance was minimal. Newly established trees were also found to be at risk from fire, typhoon, and grazing and in situations where plantations were destroyed, farmers became antagonistic towards the program. The implications of the BBN modelling for a hypothetically expanded program are that extended assistance and site inspections are necessary to eliminate planting trees on inappropriate and unsuitable sites and to improve establishment practices and weed control in order to avoid plantations of suppressed and chlorotic trees which fail to meet the expectations of farmers, thus impinging on the success of the program.

Keywords: silviculture, evaluation, mahogany, sensitivity analysis

Introduction

This paper describes the process of modelling variables which influenced the outcomes of an agroforestry extension program in Leyte Island, the Philippines. The program was undertaken as one of the activities of the Australian Centre for International Agricultural Research (ACIAR) project ASEM/2003/052, *Improving Financial Returns to Smallholder Tree Farmers in the Philippines* and the aim of the program was to assist farmers to grow seedlings in home nurseries and establish plantations of *Swietenia macrophylla* (mahogany). Because the program was designed to evaluate the effectiveness of two different levels of assistance, there was a need to identify the factors, either individually or in combination, which were the key drivers of success and in which situations this success may be maximised or overshadowed.

During the course of the program it became apparent that the effectiveness of extension activities was influenced by social, cultural, and biophysical issues and that farmers accepted some technological innovations but not others. Farmers' traditional farming skills did not prevent errors in setting out and establishing plantations or poor choice of sites. The necessity for diplomacy and tact during farm visits and during interviews meant that factors which had influenced farmers, from recruitment to tree maintenance, could not be addressed directly. Rural extension programs may be considered as an imposition of the components of the extension program (i.e. the extension system) on the farming system and in these circumstances, feedback effects are often difficult to discern (Sterman 2002). However, whenever possible, *ex-post* empirical data was collected throughout the program and this data provided the basis for an evaluation of those aspects of the extension system which were linked to the likely field performance and survival of the trees.

The difficulty in analysing the separate parts of the extension system was that many quantitative and qualitative variables were identified throughout the course of the program, the influence of which on program outcomes was uncertain. Hence, an approach to systems modelling was needed which could integrate the many factors and accommodate uncertainty in the causal relationships between them. Bayesian Belief Network (BBN) graphical models are suitable for this purpose because of their ability to model cause and effect within systems. They use probabilities to define the relationships between system variables and produce probabilistic predictions of system outcomes under specific scenarios (Jensen 1996, 2001).

BBNs are becoming an increasingly popular modelling tool particularly in ecology and environmental management because they are diagrammatic; have predictive, diagnostic and sensitivity analysis capability; allow for the integration of biophysical, economic and social variables and because they use probabilities, allow for uncertainty to be accommodated in model predictions (McCann et al. 2006, Uusitalo 2007). Hence, the use of BBNs as a modelling tool has increased in recent years, e.g. as a decision support system for water quality management (Cain 2001; Henriksen *et al.* 2007), ecological modelling, mapping and management (Lehmkuhl 2001; Walton 2006; Marcot et al. 2006) and disease diagnosis (Seidel 2003). In each case the modelling used either empirical data or expert or stakeholder opinion to assess the likelihood of variables existing in one 'state' or another, (e.g. 'water quality' as being assessed as 'high' or 'low'). The existence of variables in any particular state may be best expressed as a probability and in these situations, the capability of the Netica™ BBN modelling software produced by Norsys Software Corporation is useful to calculate the probability of variables, contingent on the probability of the occurrence of other variables.

In BBN modelling, variables which can be identified as causally influencing the outcome of other variables are linked into a network and variables lower down the chain are modified by the influence of variables higher up. BBNs therefore show the logical consequences of linking the user's understanding about parts of a system into an integrated whole and this facilitate a more compete understanding of the system (Cain 2003). Hence, for extension programs, BBNs can assist in the assessment of program success in different situations and the identification of critical success factors and stumbling blocks. These characteristics were desirable for an evaluation of this program because scaling-up the program would provide the opportunity to address those factors which had been less successfully addressed in the initial delivery. Therefore the focus of this paper is the identification of the consequences of poor site preparation, inappropriate choice of site, poor plantation establishment, maintenance and the risk of natural disasters and grazing on program outcomes. The next section provides a background to the use of BBN modelling and the use of Netica™ software. The following sections describe the methodology of the extension program and the development and results of predictive models for the growth of trees on sites of differing fertility and silvicultural input. Finally, the implications of the predictions for a hypothetical scaled-up program are discussed.

Background: Using Bayes' theorem and Bayesian belief networks for probabalistic inference

The mathematical background to BBN networks is described by Zhu and McBean (2007) and guidelines for the development of BBNs are described by Cain (2001) and Marcot *et al.* (2006). BBNs consist of nodes (boxes) which represent system variables (each node having two or more classes), links which represent causal relationships and probabilities which quantify the chance that a node will be in a particular class given that its input (or parent) nodes are in particular classes. The graphical component of a BBN is called an influence diagram and consists of nodes and links. The mathematical component of a BBN uses Bayes' theorem to calculate the probability of the occurrence of an event (a conclusion) conditional on the occurrence of other events, (a premise). The theorem is expressed mathematically by Simon (2006) as

$$P(B|A) = \frac{P(A|B)P(B)}{P(A)}$$

where

- $P(B|A)$ is the conditional probability of event B given event A. It is also called the 'posterior' probability of event B because it is derived from or depends on the specified probability of A.
- Similarly, $P(A|B)$ is the conditional probability of A given B.
- $P(B)$ is the 'prior' probability of B, in the sense that it does not take into account any information about A.
- Similarly, $P(A)$ is the prior probability of A.

In Netica™ software produced by the Norsys Software Corporation, links between variables are directed, i.e. causality is inferred from parent to child variables. Links encode the conditional dependencies between variables in conditional probability tables (CPT). Probabilities inserted into CPTs may be derived from empirical evidence or a personal belief and must be based on defensible evidence and reasoning (O'Hagen 2003). However, if the evidence is taken from a population which is being modelled, then the frequency distribution implicit in that data may be used as an approximation of the desired probabilities (Norsys 2007).

The influence of each variable on model outputs is decided by percentages or probabilities inserted into the Netica™ probability tables. Approaches to the method of inserting probabilities into the tables vary according to the type of data which is available, the use of subjective data or 'expert opinion' therefore being a feature of many models, partly because systems modelling theory suggests that omitting concepts because of a lack of numerical data is a sure route to narrow model boundaries and biased results (Sterman 2002). Hence, for this evaluation, the literature and qualitative data resulting from interviews was seen as appropriate for inserting percentages in probability tables whenever empirical data was unavailable or scant.

The software also permits the undertaking of a sensitivity analysis to examine the variation of model outputs with model inputs. Sensitivity analysis is the study of how variation in the output of a model may be apportioned to other sources of variation and of how model output depends on information fed into it (Saltelli 2000). Netica™ software provides a sensitivity analysis capability which calculates *entropy reduction* to identify those parts of a model which most affect output variables. In thermodynamics, entropy is interpreted as a measure of the disorder or uncertainty in a system and in information theory it is used in a similar manner as a measure of the uncertainty of a random variable (Liu *et al.* 2006). Hence, in a sensitivity analysis, entropy reduction may be interpreted as the amount of entropy or uncertainty at an output node or variable which is expected to be eliminated if the true value of another variable is known. Accordingly, for a chosen output variable, Netica™ software calculates the entropy reduction for other variables in the network, expressed as a percentage of the total entropy of the output variable. Calculations of entropy reduction are therefore scenario dependent and in a model of an extension program, they are useful for indicating those variables, the control of which may most improve program outputs.

Methods

Summary of the extension program

The design of the extension program was dictated by a scarcity of information concerning farmers' willingness to grow timber trees and their capacity to do so. Hence, the program was designed to provide assistance in two formats. For volunteer-farmers in the municipalities of Dulag and Libagon, assistance was provided via a field tour which included an overview of small-scale forestry. The tour was followed by extended assistance to grow seedlings and establish trees, mainly mahogany. For farmers in the municipalities of Leyte Leyte and Bato, extension assistance was restricted to the field tour, collecting seed and setting up a home nursery. Compared to farmers in Bato and Leyte Leyte, farmers in Libagon and Dulag therefore received three extra site visits, often quasi-social in nature, where in addition to assistance to set up a home nursery, they were advised how to prepare sites, plant and maintain trees. The rationale underpinning the delivery of two assistance regimes was that by the very nature of farming, most smallholders in Leyte may be expected to be experienced in planting and raising crops. If farmers were capable of establishing trees once they had been shown how to grow seedlings, then a scaled-up extension program would be more cost effective if extended assistance was not necessary.

Assistance was provided to farmers in the four municipalities from 2005 to early 2008 and wherever possible during the project, qualitative and quantitative data were collected to document the extension process and results. Although extension activities were well received, the number of farmers who participated in the program declined throughout the duration of the program (Table 1) and this prompted extension staff to document the reasons underpinning the attrition.

Table 1. Participation in extension activities by smallholders in four municipalities in Leyte

Municipality	No. farmers who initially participated in the program	No. of farmers who established trees	Site survival after one year
Libagon	13	12	11
Dulag	9	7	3
Leyte Leyte	9	3	–
Bato	9	6	–
Total	40	28	

Newly planted seedlings were destroyed by fire (one site) and flood (three sites) on steep grassland and riverbanks, respectively. One site was grazed and although no sites were destroyed by typhoons, destruction by typhoons is most probable on sites with periodically saturated soils adjacent to rice fields.

Extension staff reported that the destruction of seedlings by these natural disasters caused a change in farmers' attitude. The owners of four of the five sites became hostile and blamed the extension program for the disaster, even though ACIAR staff had not chosen the sites. In addition to complete destruction of seedlings by natural disasters, over one third of farmers neglected to remove weeds (principally *Imperata cylindrica*) around the trees with the consequence that after one year, the trees were weed-choked and chlorotic. Also, three farmers chose inappropriate planting sites - underneath a complete tree canopy in almost complete shade. Other farmers who refused or were not offered extension assistance to establish their trees also failed to stake their trees so that they could be located for maintenance (slashing weeds) and often planted new seedlings adjacent to coconuts or large trees where their growth would be impeded.

During the course of the program, it became apparent that the growth of trees and site attrition was affected by socio/economic, and cultural factors as well as biophysical causes. Elements of farmers' social and farming systems had impacted on the success of the extension system. For example, several farmers who were semi-retired, had no other use for their land and were relatively wealthy, maximised site preparation inputs in order to achieve quick growth of their trees. Some farmers also displayed an ignorance of tree establishment techniques and required assistance to achieve even simple tasks, e.g. setting-out, planting and staking trees. Variables had influenced program outcomes and that it was possible to arrange the variables as a hierarchy of influences which contributed to program outputs. Therefore for each variable, data was collected as representing different states of the variable, (e.g. site maintenance being *applied* or *neglected*). For variables relating to farm sites, this permitted calculation of the percentage occurrence of sites existing in any particular state. Where causal links between variables could be justified, this also permitted modelling the data as a BBN with the probability of the occurrence of each state being expressed as a percentage of the sample population of tree-grower farmers.

Model design

Using Netica™ BBN software, the variables were modelled as two modules (Figure 1 and Figure 2):

1. The effect of extended field assistance in maximising stand growth
2. The likelihood of sites being at risk from grazing or natural disasters.

The variables were modelled as a hierarchy of variables which influenced program outcomes. Except for general variables, e.g. farmers' wealth and motivation, data were modelled as being derived from planting sites. As far as possible, the modules constructed during this investigation followed guidelines proposed by Cain (2001) by limiting the number of parent variables to any given variable to three or fewer, so that insertion of probability data into conditional probability tables did not become overly complex. For the same reason, discrete states within any node and the depth of the modules was minimised, thus preventing the creation of a deep model in which the sensitivity of the output node to input nodes is swamped by intermediate nodes (Marcot et al. 2006).

Data was entered into the probability tables of the two modules in three ways. First, the state of variables which were used as the basis of model scenarios were set mutually exclusively as either 100.0 or 0.0% according to the scenario being modelled. For example, the level of establishment field assistance (Figure 1) was set at either 'provided' or 'not provided' (100% in each case) in the delivery of extension assistance. Second, wherever possible, empirical data which had been collected during the program was used to indicate the likely state of variables. Third, for qualitative variables where no empirical evidence was available or was inadequate, data derived from interviews and the literature were used to validate probabilities assigned in each state of each variable. Definitions of each variable and a description of the evidence used to support percentages assigned in each CPT are described in Appendix 1.

Results

The diagrammatical layout and the predicted probabilities for the various scenarios are presented in Figures 1 and 2 and Tables 1 and 2. The two modules are complementary in that they both predict aspects of the likely success of the program. Module 1 was run for scenarios in which establishment field assistance and site inspections were offered together. Module 2 was run for scenarios in which the incidence of fencing to prevent grazing was either 21.4% (as experienced through the program) or 100%, i.e. if every site was fenced.

Module 1 reflects field observations that the effect of unsuitable sites, mostly sites underneath a full tree or coconut canopy, has little effect on initial tree growth but after several years the trees will become etiolated and spindly. Similarly, planting trees adjacent to established trees was observed to have little effect on the initial growth of the trees but will become apparent several years later. The effect of neglected site maintenance (weed control) was most evident on infertile sites. Trees which initially showed poor growth, were chlorotic and choked by weeds and in very poor health if weed control was not maintained. However, on the few infertile sites where weed control had been maintained, trees were observed to be healthy and of good colour, even if their height was reduced.

The predicted probability of the three states of *initial stand growth* (at one year of age) and the corresponding three states of the variable *subsequent growth* (Table 2) is that trees in less than 10% of stands will be exhibiting healthy vigorous growth, for either scenario. Low site fertility, often in combination of minimal site preparation inputs combine to produce plantations where tree growth is *healthy but slow* (60.1%) or *poor and chlorotic* (30.4%). In subsequent years, the impact of inappropriate establishment procedure and inappropriate site selection is seen in a predicted probability of 2.7% of sites showing tree growth that may be described as 'site optimal', 49.4% of sites where tree growth is reduced and 47.9% of sites where predicted tree growth is very low.

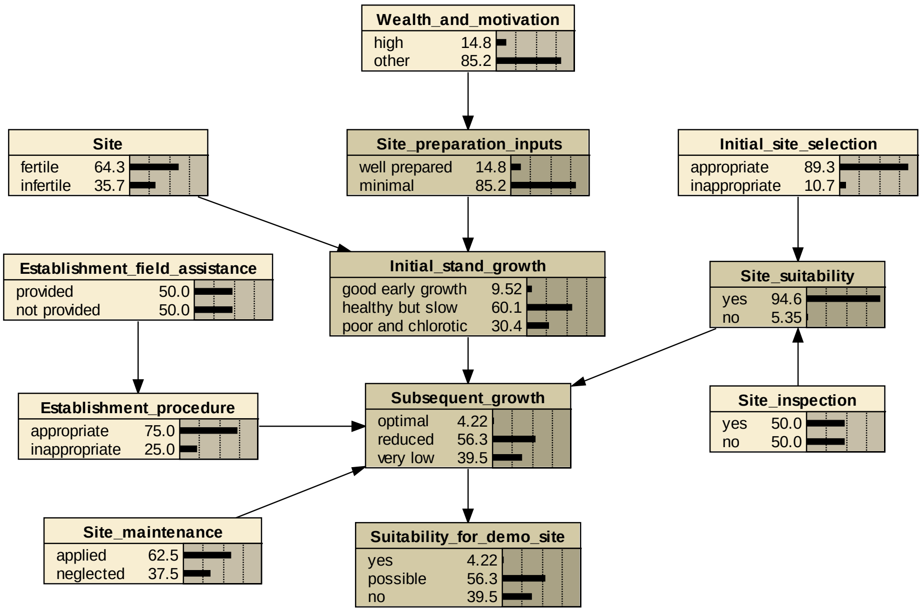

Figure1. Module 1: Probable initial and subsequent stand growth for varying levels of establishment field assistance and site inspections.

At one year of age, the predicted probability of sites being at risk of being destroyed is much higher for grazing (7.1%) than either typhoons (1.8%) or fire (1.7%) (Table 3). These scenarios only included those low-lying sites with a high water table as being at risk of typhoon damage. It could be expected that a severe typhoon may inflict more damage to trees. Also, fires are a perennial problem in the Philippines, but the incidence of fire is very much related to the dryness of the season and consequent drying of grass. The major risk to young trees is therefore damage from the ever-present water buffalo.

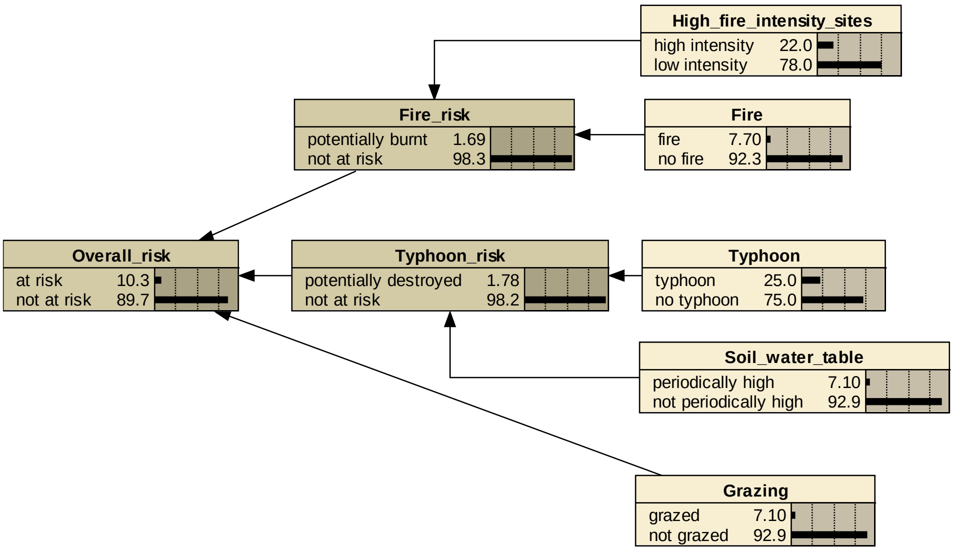

Figure 2. Module 2: Probable risk of sites to destruction from natural disasters and grazing.

Table 2. Predicted probability of subsequent stand growth (one year onwards) in situations where establishment field assistance and site inspections are alternatively provided or not

		Predicted probability (%)	
		Establishment field assistance and site inspection	
Variable	**State**	**Provided**	**Not provided**
Initial stand growth (one year)	Vigorous	9.5	9.5
	Good colour, slow growth	60.1	60.1
	Poor and chlorotic	30.4	30.4
Subsequent growth (succeeding years)	Site optimal	5.9	2.7
	Reduced	63.6	49.4
	Very low	30.4	47.9

Table 3. Predicted overall risk of destruction of planted trees from fire, typhoon and grazing

Variable	**State**	**Predicted probability (%)**
Fire risk	Potentially burnt	1.7
Typhoon risk	Potentially destroyed	1.8
Grazing	Grazed	7.1
Overall risk	At risk	10.3

The sensitivity analysis indicated that the variable *subsequent growth* was more sensitive to variation in *site suitability* (6.3%) than *site maintenance* (3.3%) and *establishment procedure* (3.2%), (Table 4). The low entropy reduction of all three of these input variables was predicated by the (not unexpected) very large entropy reduction of *initial stand growth* (60.2%) on *subsequent growth*. Similarly, the very large entropy reduction of *grazing risk* (58.1%) on *overall risk* compared to *typhoon risk* (12.6%) and fire risk (12.0%) (Table 5) indicates again that in this program, grazing by water buffalo is the primary risk to young trees.

Table 4. Sensitivity (expressed as entropy reduction) of the output variable *subsequent growth* to variation in *establishment procedure, site maintenance* and *site suitability*

Variable	Entropy reduction (%)
Establishment procedure	3.2
Site maintenance	3.3
Site suitability	6.3
Initial stand growth	60.2

Table 5. Sensitivity (expressed as entropy reduction) of the output variable *overall risk* to variation in *fire risk, typhoon risk* and *grazing risk*

Variable	Entropy reduction (%)
Fire risk	12.0
Typhoon risk	12.6
Grazing risk	58.1

Discussion

For module 1, both modelling scenarios and the sensitivity analysis indicated that achieving good early stand growth is of primary importance. The nature of the program was such that farmers were permitted to choose site preparation inputs, even though it was made clear to them that maximising site preparation (e.g. through ploughing) would enhance early-age growth. Given this option, most farmers minimised site preparation, only those farmers with disposable income investing in ploughing, fertilising and early-age weed control. The implication for an expanded program is that unless farmers can be convinced to apply intensive site preparation, infertile and neglected sites may become weed choked, chlorotic and suppressed.

In discussions, farmers indicated that they were well aware of the risk of grazing, and yet only six of 28 farmers erected fences around their trees. While the time and expense of erecting fences may be a burden to poor farmers, the low incidence of fencing on the 19 sites which were susceptible to grazing indicates that farmers decided to accept the risk of sites being grazed. Given the considerable commitment which farmers made to other aspects of the program, farmers' reluctance to fence sites is difficult to understand. While the models highlight the importance of achieving early age stand growth and minimising grazing, the other causes of or site destruction should not also be dismissed. Extension staff discounted the influence of sites which were destroyed by flooding, because the sites were considered atypical. However, the negative reaction of farmers whose sites were destroyed by any cause showed that bad publicity resulting may result from events which are not within program managers' power to control.

For a hypothetically expanded program, the implications of both models are that while identification and prioritisation of the constraints to the success of the program may be achievable, a remedy may be more difficult. Eliminating unsuitable sites can be achieved through a site inspection and unsuitable establishment practices can be the focus of further extension work. However, for program managers who are familiar with plantations in developed countries where intensive site preparation maximises early-age growth, the high percentage of sites with 'reduced' tree growth may not be acceptable as a program outcome. Having almost half of sites with 'very low' growth rates is also unlikely to be acceptable to Filipino farmers and reduces the use of many sites for demonstration purposes. Although the current ethos of extension is to allow farmers to choose which inputs suit their purposes, the results of this model imply that a more prescriptive approach may be appropriate.

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Appendix 1. Definition of variables used in the modules and summarised supporting evidence

Module 1	
Variable	**Definition and summarised supporting evidence**
Wealth and motivation	Farmers wealth is defined as 'high' when they indicate that they have no need to work actively on their land, and have discretionary income, (often as a retirement pension or as a remittance). In other circumstances, farmers wealth is defined as 'other'.
Site	Sites are defined as being 'infertile' if they are situated on steep, eroded and obviously impoverished land. In other circumstances sites are defined as being 'fertile'.
Site preparation inputs	Site preparation inputs are defined as being 'well prepared' when weeds are controlled and the sites are ploughed or extensively hoed. Site preparation is defined as 'minimal' when sites are cleared (often burnt) and trees are planted directly into the soil.
Initial stand growth	At one year of age, initial stand growth is defined as 'good early growth' when trees are healthy and growing vigorously, often 2-3 m tall; 'healthy but slow' when trees have good colour but are reduced in size, often 1-2 m tall and 'poor and chlorotic' when trees are less than 1 m tall, chlorotic and were obviously having difficulty establishing themselves through weeds.
Establishment field assistance	Establishment field assistance is defined as the provision of field assistance to farmers to set out, plant and stake seedlings.
Establishment procedure	Establishment procedure is defined as being 'appropriate' when farmers space trees at least 4 m away from competing trees or coconuts and stake newly planted seedlings so that they can be located for the purposes of weeding.
Site maintenance	Site maintenance is defined as being 'applied' when weeds are regularly slashed around newly planted seedlings so that the seedlings do not become choked by weeds.
Initial site selection	Initial site selection is defined as being 'appropriate' when the canopy cover of the site is sufficiently sparse that newly planted seedlings experience full sun for most of the day.
Site suitability	As above, sites are defined as being suitable or not.
Site inspection	A site inspection is defined as a field visit in which farmers are offered advice about planting sites.
Subsequent stand growth	Subsequent stand growth was defined as being 'optimal' when trees are healthy and growing vigorously; 'reduced' where trees are healthy but are reduced in growth, reflecting site or establishment limitations and 'very low' when trees are stunted, of poor colour and not actively growing.
Suitability for demonstration site	As above.

Appendix 1. (cont).

Module 2	
Variable	**Definition and summarised supporting evidence**
High fire intensity sites	High fire intensity sites are defined as being sites which are dominated by annual grasses. These sites are often steep. Sites which are covered with soft green weeds or no vegetation are defined as being ‘low intensity’. Trees planted on a ‘high fire intensity’ site would be destroyed by a fire but trees on a ‘low fire intensity’ site would not be destroyed.
Fire	Fire is defined as the incidence of fire on the sites planted during the program.
Fire risk	Fire risk is defined as the combined probability that a site will be ‘high risk’ and destroyed by fire.
Typhoon	Typhoon is defined as being the incidence of severe typhoons in the Philippines – described by Dart et al. (2001) as being 25% in any one year.
Soil water table	Soil water table is defined as being ‘periodically high’ when seasonal rainfall causes the water table to rise so that the soil saturated layer is less than 0.5 m from ground level, leading to shallow rooting and wind-throw in typhoons.
Typhoon risk	Typhoon risk is defined as being the combined probability of the incidence of a typhoon and a site having periodically saturated soils.
Grazing	Grazing is defined as being the probability of vulnerable sites being grazed.
Grazing risk	As above.
Overall risk	Overall risk is defined as being the risk of a site being destroyed by natural disasters or grazing.