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A systems approach to improving the quality of tree seedlings for agroforestry, tree farming and reforestation in the Philippines

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ABSTRACT

The limited supply of high quality planting materials for a wide species base is a major reason for the limited success of reforestation programmes or projects in many developing countries. This paper reports the research that was undertaken to improve the supply of high quality planting materials for agroforestry, tree farming and reforestation in the Philippines. A systems approach was used to identify mechanisms to improve the operational effectiveness of the forest nursery sector. A Bayesian Belief Network of the forest nursery sector was developed to examine the interactions between the key components of the forest nursery sector, identify key leverage points for intervention and explore potential impacts of possible policy interventions. Although improving the operational effectiveness of individual, communal and government nurseries will result in high operational effectiveness of the forest nursery sector, the operational effectiveness of government nurseries is likely to have a negative impact on the market for seedlings from smallholder nurseries i.e. individual and communal nurseries, thus impeding the sustainability of smallholder nurseries. Increasing the supply of high quality germplasm for a wide variety of species, improving the technical capabilities of smallholder nursery operators in seedling production and increasing the market demand of high quality seedlings from smallholder nurseries are the most important requirements for improving the operational effectiveness of the forest nursery sector. However, government nurseries can play a crucial role in improving the effectiveness of the forest nursery sector by diversifying their production to focus on species that are in demand by smallholder farmers and which cannot be supplied by individual or communal nurseries. Failing to do this will result in the current situation continuing in which government nursery sector competes with private and communal nurseries.

Introduction

The success of agroforestry, tree farming and reforestation initiatives in many developing countries is often constrained by the lack of planting materials and low quality of planting stock (Aalbaek, 2001; Noordwijk et al., 2003; Harrison et al., 2008a). The lack of planting materials and low quality of planting stock can be attributed to a plethora of factors including the lack of technical skills to produce high quality seedlings, the limited access of seedling producers to high quality germplasm, the absence of incentives to produce high quality planting stock, and the lack of appreciation of tree farmers on the importance of seedling quality (Gregorio et al., 2010a; Nyoka et al., 2014). In addition, often the metrics to measure performance of reforestation are associated with government or NGO targets for number of trees planted rather than the long term performance of those trees (see Le et al., 2012, 2014) and this results in the limited concern of the agencies responsible for watershed rehabilitation to ensure the use of high quality seedlings in reforestation, agroforestry and tree farming programmes (Nyoka et al., 2014).

In the tropics, nursery-grown seedlings are the commonly used planting stock for plantation forestry (Evans and Turnbull, 2004), including trees for community-based forestry programmes and agroforestry. Accordingly, the quality and availability of planting stock is largely influenced by the operational effectiveness of the nursery sector (Degrande et al., 2013; Nyoka et al., 2014). In the Philippines, while seedlings for watershed rehabilitation programmes are supplied by nurseries from private and government sectors, low seedling quality and limited availability are still regarded as major impediments to the scaling up of smallholder forestry (Gregorio et al., 2008, 2010a,b; Harrison et al., 2008b) and

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improving the success of reforestation programmes in the country (Lapis et al., 2001; Combaliser et al., 2010; Israel and Lintag, 2013). In addition, poor silviculture of smallholder and community woodlots has resulted in poor timber yields relative to site potential (Herbohn et al., 2014) and use of higher quality seedlings is likely to lead to improved yields of timber from reforestation activities with a timber production component.

The paradigm shift of forest management to people-based forestry has transferred the bulk of seedling production to private seedling producers and community organisations. Training programmes have been provided to seedling producers but these initiatives failed to increase the supply of high quality seedlings for reforestation projects and private tree plantations in the Philippines (Lapis et al., 2001; Tolentino et al., 2002). A review of literature revealed that there is dearth of knowledge about the operational effectiveness of the forest nursery sector in the Philippines. While some limited research has been carried out regarding the technicalities of producing high quality seedlings, there has been no comprehensive investigation of the management practices and organisational systems of the forest nursery sector.

To investigate ways in which the supply of high quality planting materials to smallholder tree farmers can be increased, a study was conducted on the forest nursery sector of Leyte Province. The purpose of the study was to examine the interactions between the components of the forest nursery sector, develop a nursery sector model to identify key leverage points for interventions, and use the nursery sector model to explore potential impacts of possible policy interventions.

This paper describes the participatory development of a Bayesian Belief Network (BBN) to model the forest nursery sector in Leyte, the Philippines and the subsequent application of this model to identify potential interventions or leverage points to improve the operational effectiveness of the forest nursery sector. The paper commences with an overview of BBNs as a tool for policy analysis. This is followed with a description of the study site and the nursery sector in Leyte. The development and structure of the BBN model for nursery effectiveness is then outlined. The results of the application of the model to identify important leverage points are presented and the key policy implications are discussed.

Research method

An overview of Bayesian Belief Network

Bayesian Belief Networks (BBNs) are conditional probability models in graphical form that show the cause and effect relationships between variables within systems (Jensen, 2001). They consist of nodes that represent system variables, links that represent causal relationships between nodes, and probability tables that quantify these relationships using conditional probabilities. BBNs can be used for predictive, diagnostic and sensitivity analyses, and because they use probabilities to relate variables, they explicitly allow uncertainty to be accommodated in predictions. These BBN attributes have made them attractive to a number of disciplines (including medicine, engineering, information technology, ecology and environmental management) that use a systems approach in decision-making, whilst accommodating uncertainty of evidence. In natural resource management, BBNs have been particularly useful for capturing, integrating and presenting knowledge about ecological and socio-economic systems (see McNay et al., 2006; Pollino et al., 2007; Smith et al., 2007). BBNs have been used to engage stakeholders and natural resource managers in systems analysis and decision-support utilising both expert opinion and empirical data in modelling systems (see Cain et al., 2003; Smith et al., 2005, 2007; McCann et al., 2006; Bosch et al., 2007; Baynes et al., 2011). BBNs have also been applied to the adaptive management of natural resources (Nyberg et al., 2006; Henriksen and Barlebo, 2007). Although regarded as a user-friendly and versatile decision support tool, the BBN has a limitation of increasing dilution effect of impacts of interventions with increasing distance between the intervention and objective nodes within the model structure. This shortcoming can be offset through careful design of the model in such a way that it closely represents the real world.

The diversity and complexity of factors that influence the operational effectiveness of the forest nursery sector in Leyte Province, and the limited experience of stakeholders in using models in decision-making, make BBNs a highly suitable systems analysis tool for identifying interventions to improve the operational effectiveness of the forest nursery sector. In this study, a BBN was used to piece together the network of influences among key biophysical and socio-economic factors believed by the researchers to affect the supply of high quality planting stock within the Leyte nursery sector. Then, through scenario and sensitivity analysis capabilities, the BBN has been used to identify policy interventions that are potentially useful to solve the problem of limited availability of planting stock and low access of smallholders to high quality planting material.

Description of the forest nursery sector and the study site

Leyte Province has a total land area of 626,826 ha of which 35% is classified as timberland[2]. As of 2010, the province of Leyte had a population of 1.73 M (NSCB, 2010). Agriculture plays an important role in the economy of the province. The majority of the farmers in Leyte province have landholdings of not more than 5 ha (Groetschel et al., 2001). The main source of income for most of the population is the production of agricultural crops (mainly rice, abaca and copra), raising livestock and harvesting marine products.

As in most parts of the Philippines, forests were the major natural resource on Leyte Island in the early 1900s. Large-scale logging operations and conversion of forestland to agriculture, however, have largely resulted in a massive decline of forest cover on the island (Groetschel et al., 2001). Many attempts have been made by the Philippine government and international support agencies to rehabilitate the denuded uplands and halt destruction of the remaining forest. The most recent initiative is the promotion of community forestry, which recognises people as a vital component of the entire forest protection and rehabilitation process.

The bulk of seedlings used in smallholder forestry come from the three nursery groups – private, communal and government-owned. Private nurseries are usually established by individual farmers and are operated with the help of family members to produce planting stock, mainly for use on their own farm. A number of private nurseries also sell seedlings to other farmers and sometimes to government agencies. Most of these nurseries were established in response to the difficulty in obtaining planting stock from government nurseries, which are usually far from villages and hence inaccessible to most smallholders. The nursery is usually temporary in nature and is generally established next to the house of the operator for ease of maintenance and security against pilfering and stray animals. This type of nursery usually continues to operate for more than one planting season. Although most of the nurseries are established primarily to produce planting stock for personal use, the nursery operation is usually flexible to shift to commercial production whenever an opportunity to sell seedlings arises.

Communal nurseries are established by a group of people in the community for the purpose of producing planting stock for

[2] In the Philippines, the DENR classifies all rural land in the public domain with a slope of 18% and above as *timberland*.

communal planting, sale, or distribution to members of the organisation. Usually, these are project-initiated and the people are organised by supporting agencies to act as partners in implementing a forestry project e.g. a project under the Community-based Forest Management Program. In this type of nursery, the seedling production schedule, quantity of planting stock and species raised are decided jointly by the community organisation and supporting agency. In most cases, participating members are paid for raising the seedlings and a formal protocol exists for sharing of future benefits from community use and sale of timber. The nursery is often located centrally within the community for easy access by all members. Unlike private nurseries, shifting to commercial seedling production is uncommon for communal nurseries. The operation of communal nurseries usually ceases after the volume of seedlings required for a community-planting plan is satisfied.

Government-owned nurseries are usually situated in a major city or town. Seedlings are produced mainly for the purpose of free distribution to all interested parties. Experienced workers who are paid on either a contract or regular basis usually carry out the seedling production activities and the volume of seedlings produced is normally higher than that of individual and communal nurseries. With a well-established structure, this type of nursery is usually permanent in nature.

Modelling the forest nursery operational effectiveness

The model was developed around the three nursery groups – private, communal and government – which are the major source of planting materials used in community and smallholder forestry. A survey of nursery operators was conducted using a semi-structured questionnaire. Inasmuch as no comprehensive list of nurseries in the three ownership groups was available, these were identified through snowball sampling. All 74 nurseries, which could be identified in the three ownership categories, were included in the survey.

Survey questions were structured to elicit information on nursery seedling production methods, nursery operation systems, technical skills of nursery managers, nursery set-up, volume of seedlings produced, nursery facilities and inputs, pathways of germplasm and seedlings, and constraints encountered in nursery operation. Data collected from the face-to-face interviews with respondents were supplemented with information obtained from the focus group discussion with key stakeholders to identify additional key variables and dependencies. Information gathered from the literature, records obtained from nursery operators and supporting agencies including the Department of Environment and Natural Resources (DENR) and Department of Agriculture (DA), and the experience of the chief investigator were also used to supplement the primary data. Statistical summaries including frequency counts, measures of central tendency (mean and median) and measures of dispersion (standard deviation) were extracted to provide an initial understanding of the data gathered. Where appropriate, the data were used for further statistical analysis including χ^2 tests and one-way Analysis of Variance (ANOVA) to determine the relationships among survey variables. For example, χ^2 tests were carried out to investigate whether any relationship exists between educational background and tree farming experience of seedling producers to their knowledge on site-species matching. Similarly, an ANOVA was used to determine if seedling sales were related to distance of the nursery from the main road, and if interest of seedling producers to attend forestry training activities is related to having planted trees. Results of these tests were used as input in designing the model, particularly in establishing links between variables.

Based on the analysis of the survey data and the supplementary information, an influence diagram (box and arrow diagram) was constructed for each of the three nursery groups to represent the dependencies among key variables influencing effectiveness within each group. The influence diagrams for the three nursery groups were then linked to form the influence diagram of the entire forest nursery sector. The influence diagrams were converted into a BBN using NETICA™ software (Norsys Software Corporation, 1998) by indicating states for each variable and populating conditional probability tables (CPTs). The states are probable conditions of the variable in the real world. These were initially determined using the information obtained from the survey, opinion of the researcher and inputs from forestry experts of the Visayas State University. Almost all nodes were assigned with binary states representing the most positive and most negative expected levels. The CPTs were populated using the survey data and other records collected in the supplementary information (Information Type 1 – see Cain, 2001). In cases where survey data were not available to populate CPTs of some nodes, expert opinion based on best judgement and theoretical calculation of probabilities for each state to occur were used to populate the CPTs (Information Type 4 – see Cain, 2001). The probabilities of CPTs populated using the Type 1 data or information were computed following the *approximate learning method* (see Cain, 2001).

Table 1
A section of the form used in eliciting probabilities for the private nursery sector.

Child variable	Parent 1	Parent 2	Elicited probability	
Individual nursery effectiveness	Sustainability	Seedling quality	High	Low
	Yes	High		
	No	High		
	Yes	Low		
	No	Low		
Seedling quality	Genetic quality	Physical quality	High	Low
	High	High		
	Low	High		
	High	Low		
	Low	Low		
Seedling physical quality	Technical skills	Germplasm physical quality	High	Low
	Expert	High		
	Inexpert	High		
	Expert	Low		
	Inexpert	Low		

A workshop with key stakeholder representatives was conducted at Visayas State University to review the BBN structure. The brainstorming process was carried out in a series of stages adopting the face-to-face Delphi technique (see Chia-Chien and Sanford, 2014). Initially, the participants were divided into three groups based on the nursery group they represented. The purpose of this grouping was to discuss, criticise and revise, whenever necessary, the BBNs of each nursery group. To facilitate the review of the BBNs, they were broken down into a series of lists whereby all child or dependent variables[3] were listed in one column and the parent or independent variables[4] influencing each child variable were given in columns beside the appropriate child variable. A section of the list of variables for the individual nursery group, which was presented during the workshop is presented in Table 1. All the participants were then brought together to examine the graphical structure, names of the nodes and states, and CPTs of the variables of the BBNs of the three nursery categories, especially those with probabilities generated through subjective estimates.

The review resulted in only minor changes of the BBN structure and CPT values. This was expected because the model was

[3] Child variable is a variable in the BBN that has links feeding into it from other variables.

[4] Parent variable is a variable in the BBN that has links going out of it to other variables

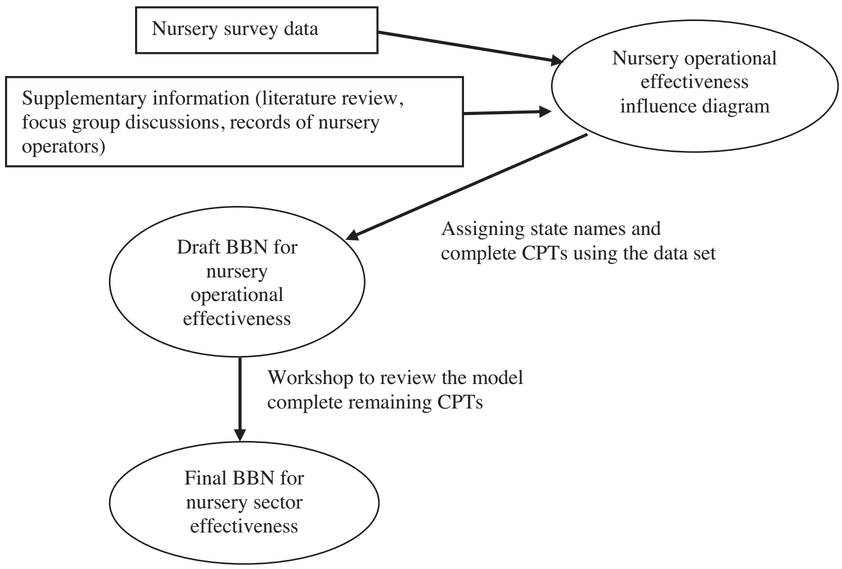


Fig. 1. Steps in the development of BBN for nursery operational effectiveness.

developed based on empirical data and opinions of experts. After finalizing the structure of the BBNs and examining the probabilities, the participants worked again as separate groups to fill in the conditional probability tables (CPTs) of selected nodes in the model that could not be populated with the survey data but for which they had expertise. Each of the three groups then presented their output in a combined session. Subjective estimates of probabilities provided by each group were scrutinized by participants and in some cases revised when deemed inappropriate. The BBN for each of the three nursery ownership groups were then linked by connecting the individual, communal and government effectiveness outcomes to an overall outcome called *operational effectiveness* of the nursery sector. Appendix A summarises the variables, states and sources of data used to develop the final forest nursery operational effectiveness model. An outline of the steps used in the model development process is presented in Fig. 1.

The model was used to carry out simulation tests and scenario analyses to understand the complexity of the forest nursery system. The probability values of states describe the node performance as either high or low. Variables with probability values of more than 60% on the negative state are considered as having low performance. Through simulation experiments and scenario analysis (as explained in Cain, 2001), the model was used to determine the effect of making improvements in areas of low performance on the overall operational effectiveness of the forest nursery sector. In this way, the scenario and sensitivity analyses provided a means to identify potentially effective policy interventions.

Sensitivity analysis is used to determine the relative influence of a single variable (node) or array of nodes on another variable in the network. For categorical states, sensitivity analysis is a calculation of entropy reduction, while for continuous states, variance reduction is used. In the nursery effectiveness BBN, results of sensitivity analysis are expressions of entropy reduction.

Entropy reduction is 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. In symbolic form, entropy is expressed as $I = \Sigma q \Sigma f \mathrm{P}(q,f) \log[\mathrm{P}(q,f)/\mathrm{P}(f)]$,where q is the state of the query variable Q, f is the state of the findings variable F, and the summation is over all states q and f of the variables Q and F. The higher the entropy reduction value, the greater is the influence of a particular factor on the factor under investigation.

Results and discussion

Analysis of the operational effectiveness of Leyte nursery sector

The nursery operational effectiveness model is presented in Appendix B. A simulation test using the model suggests that *sustainability* of the smallholder nursery (private and communal) operation is strongly influenced by *seedling demand*. The probabilities of a high demand on the planting stock from individual and communal nurseries are 27.6% and 47.7%, respectively. However, when evidence is entered so that the *government nursery effectiveness* is high, the probabilities that there would be a high *seedling demand* from the individual and communal nurseries is dramatically reduced to 7.2% and 9.7%, respectively. Findings from the nursery survey revealed that there is duplication of most species raised between smallholder and government nursery groups. Thus, increasing the availability of free seedlings of a particular species from the government nursery group would likely result in low seedling market opportunities for these species produced by smallholder nurseries.

Inasmuch as *seedling demand* is a highly important factor that sustains the operation of smallholder nurseries, a reduction in sales (such as would be the case if government nurseries were producing the same species and the distribution of these were free of charge) obviously would be detrimental to smallholder nursery operations. Recognising that the *operational effectiveness of the nursery sector* can only be achieved when all the nursery groups are effective in their operations, it is clear that appropriate organisation and coordination among nursery groups is essential. Deciding how to organise the nursery sector activities requires a thorough understanding of the performance of each group of the nursery sector and their interactions.

The operational effectiveness of the individual nursery group

Key areas in the individual nursery group with low performance include the *production budget*, *seedling quality*, *technical skills* and *sustainability* of nursery operation. In the baseline scenario (Fig. 2), the operational effectiveness BBN for the individual nursery sector predicts that the probability of high *individual nursery effectiveness* is only 32%. This is attributed to the widespread production of low quality seedlings [p(low) = 76.3%] and high probability of unsustainable seedling production [p(no) = 59.7%]. The low quality

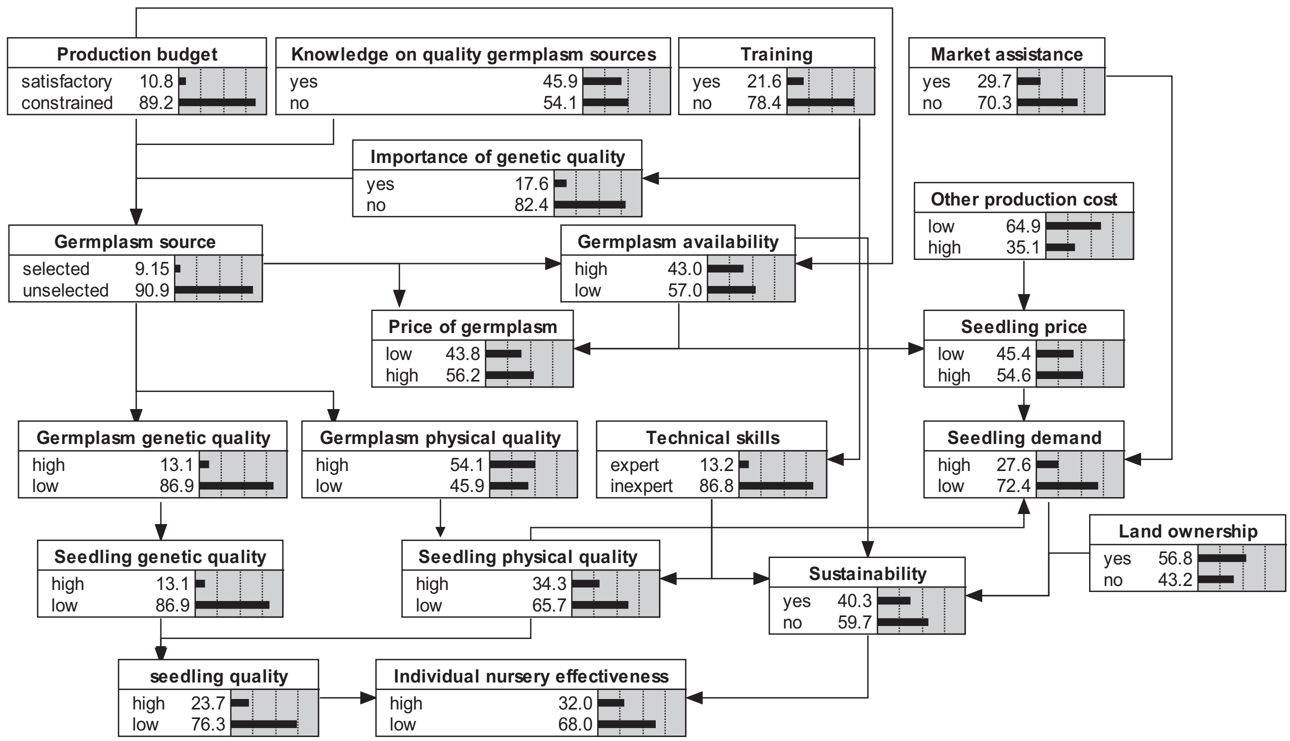


Fig. 2. BBN for the private nursery group showing the baseline scenario.

of seedlings is attributed to the use of germplasm that is collected from unselected sources (approximately 91% of nurseries). A sensitivity analysis of factors affecting the selection of *germplasm source* reveals that the *production budget* has the least influence while the operators' *knowledge on high quality germplasm sources* has the greatest influence (Table 2). While the cost of accessing germplasm of superior quality is usually a prohibitive factor to smallholders, the sensitivity analysis results indicate that private nursery operators have a greater chance of using genetically superior planting materials if they have access to information about potential sources.

The scenario analysis presented in Fig. 3 shows that if nursery owners have satisfactory *production budget*, with low appreciation of the *importance of genetic quality* of germplasm [p(no) = 82.4%] and with limited *knowledge on high quality germplasm sources* [p(no) = 54.1%], the probability of nursery operators collecting germplasm from selected sources is very low [p(selected) = 8.8%]. This finding suggests the need for an information campaign to make seedling producers aware of the benefits of using genetically superior germplasm and the importance of planting genetically superior seedlings. Also, the result suggests the need to provide nursery seedling producers with information about the sources of high quality germplasm.

The *sustainability* of the private nurseries is directly influenced by the sufficiency of *germplasm availability*, substantial *seedling demand*, appropriate *technical skills* of operators in seedling production and *land ownership*. Among the influencing factors, *germplasm availability* has the greatest influence on the *sustainability* of seedling production (Table 3). This suggests that as long as germplasm is readily available, there is a high likelihood that seedling production will continue even if seedling demand is low. During the survey of forest nurseries it was commonly observed that nursery operators, despite there being no prior seedling order, produced seedlings. However, the volume of production in these cases was low and intended mainly to advertise the seedling production business.

Improving the *germplasm availability* without any regard to *germplasm genetic quality* raises the probability of high *individual nursery effectiveness* by only 9.2%. When operators use genetically superior germplasm the probability of high nursery effectiveness increases by only 20.3%. This minimal increase is attributed to the reduction of *germplasm availability* by 21.5%. The nursery survey revealed that the supply of germplasm with high genetic quality is very limited. However, if the scenario where operators use high genetic quality germplasm and the availability of the genetically superior germplasm is high, operational effectiveness of the individual nursery group increases from 32.0% to 65.7%, an increase of 33.7%. This suggests that increasing the supply of high quality germplasm is important for improving *individual nursery effectiveness*.

Seedling demand is another factor that influences the *sustainability* of private nursery operations, especially for those nurseries that have ventured into commercial seedling production. The current situation is that there is low *seedling demand* [p(low) = 72.4%] and that most individual nurseries operate without any *marketing assistance*. In addition, the low *seedling physical quality* affects sales. The sensitivity analysis presented in Table 4 reveals that providing

Table 2
Sensitivity analysis of factors influencing germplasm sources of private nurseries.

Influencing node	Entropy reduction
Knowledge on quality germplasm sources	0.07917
Importance of genetic quality	0.00334
Production budget	0.00001

Table 3
Sensitivity analysis for influencing factors on production sustainability of private nurseries.

Node	Entropy reduction
Germplasm availability	0.11619
Seedling demand	0.04076
Land ownership	0.01504
Technical skills	0.00904

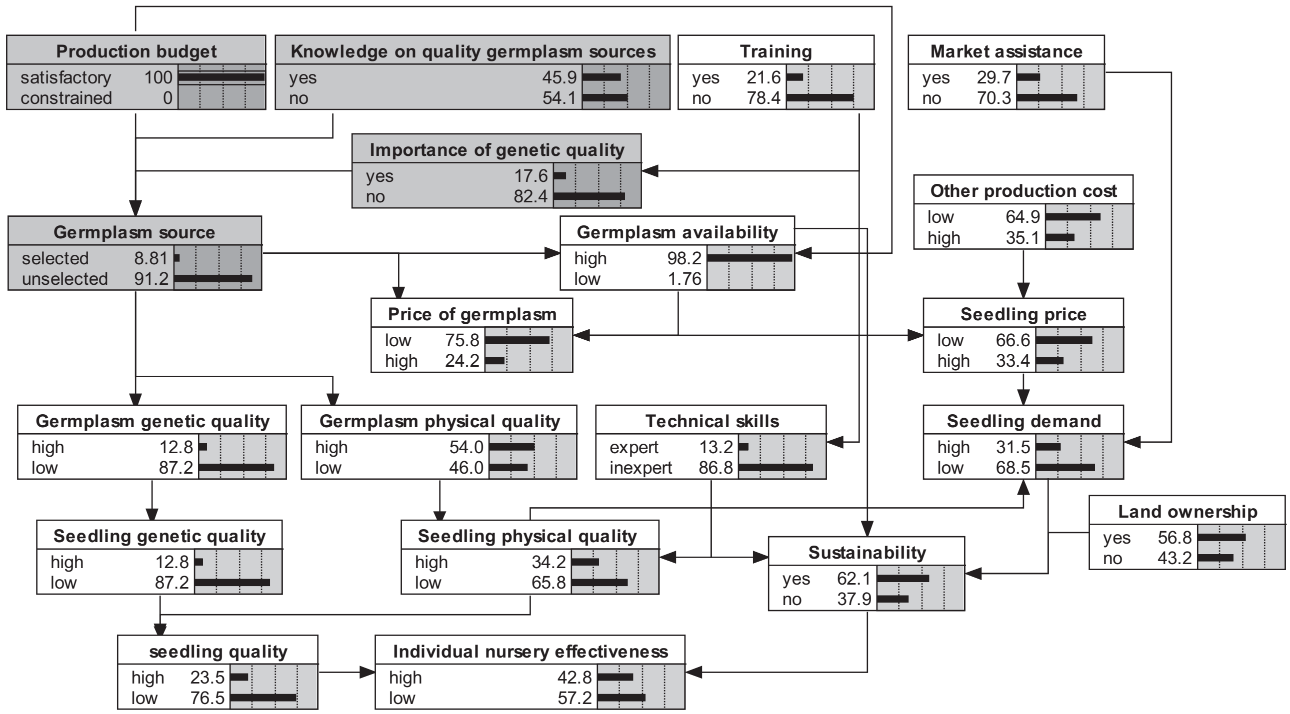


Fig. 3. BBN for the private nursery group showing the limited impact of production budget on germplasm sources.

marketing assistance is likely to have the largest impact on *seedling demand*.

The *technical skills* of nursery operators appear to be an important factor affecting both *seedling quality* and *sustainability* of nursery operation. However *training*, which directly affects *technical skills*, has little influence. Scenario analysis suggests that, given all nursery operators attend training classes, the technical expertise only increases by almost 2% (from 13.2% to 15%) (Fig. 4). This is almost counter-intuitive because training is often seen as a key

Table 4
Sensitivity of seedling demand in private nurseries to findings of influencing variables.

Node	Entropy reduction
Market assistance	0.10571
Seedling price	0.03036
Seedling physical quality	0.00803

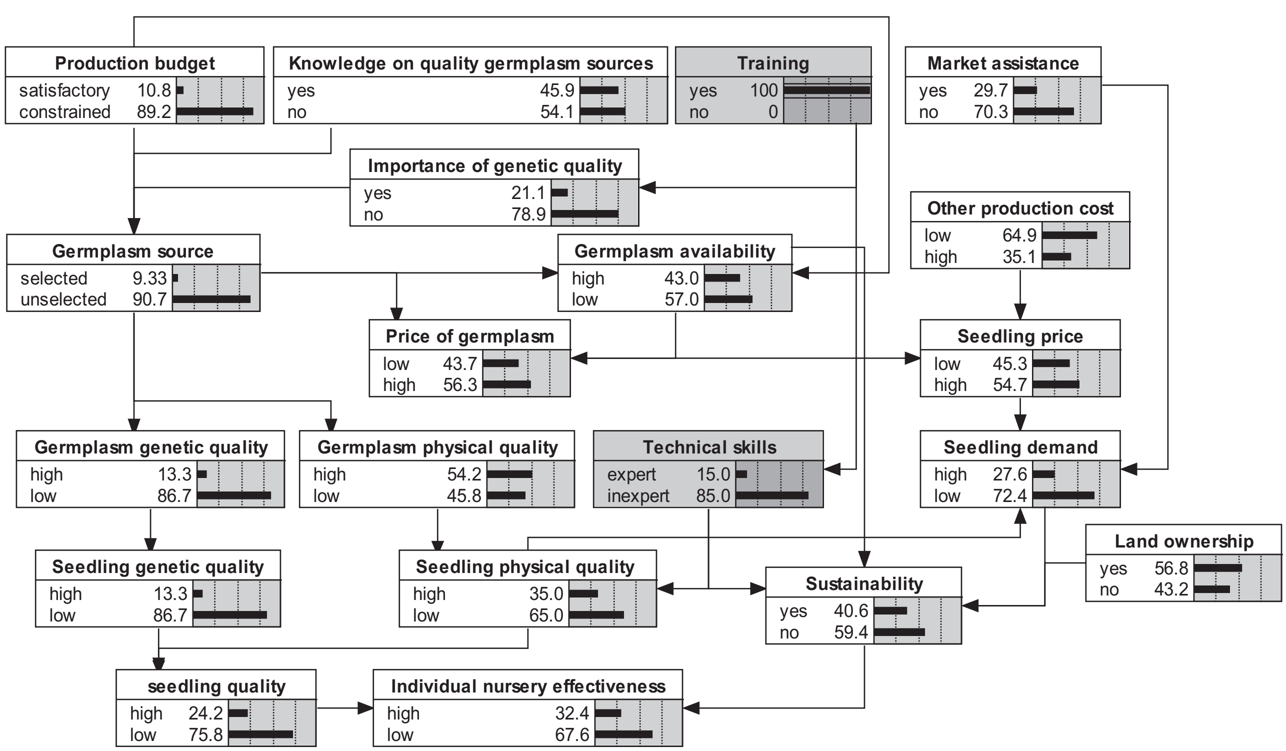


Fig. 4. BBN for the individual nursery group highlighting the minimal impact of training on improving the technical expertise on private nursery operators.

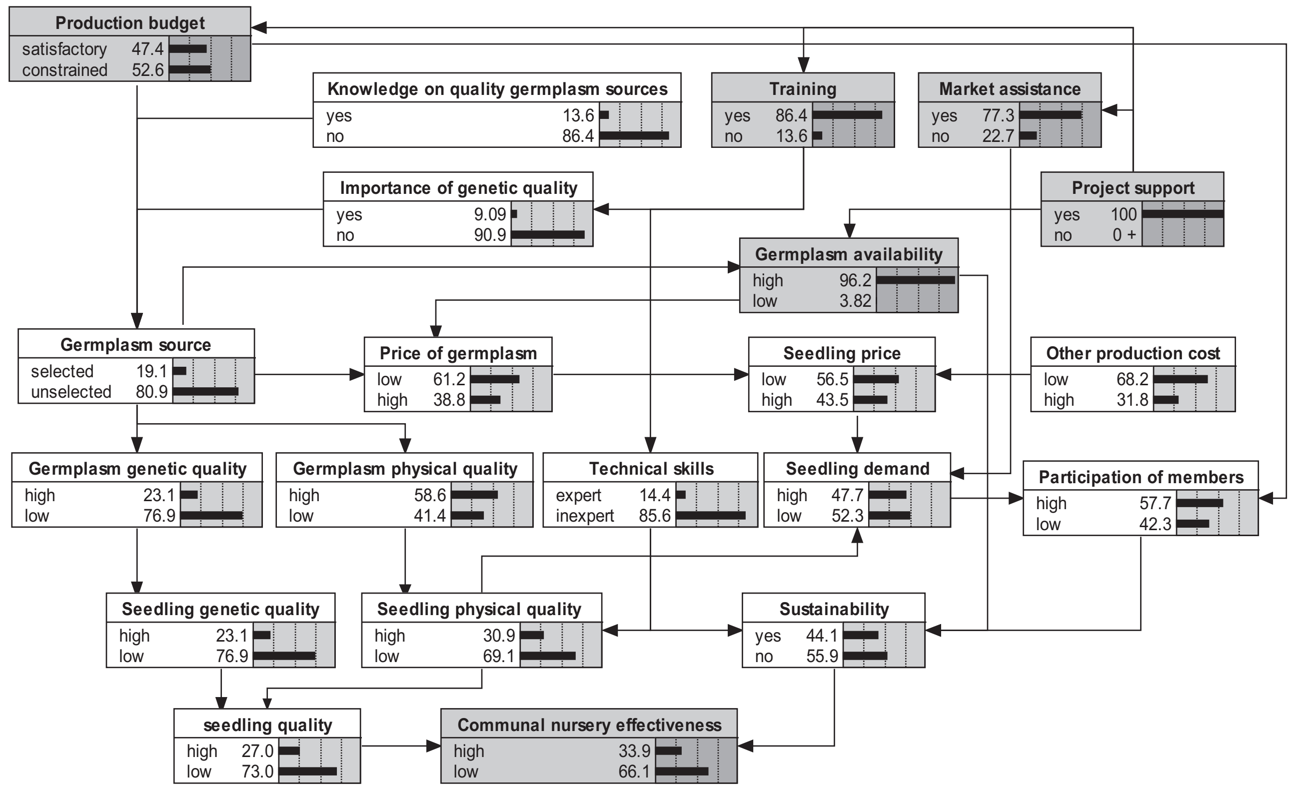


Fig. 5. BBN for the communal nursery group showing the direct influence of project support on training, production budget, availability of germplasm and market assistance.

intervention. Detailed discussion at workshops with stakeholders revealed that this is in fact logical. It was largely indicated that the current training provided by support agencies is ineffective, not suited to the needs and learning styles of the operators. For instance, the training is often theoretical and does not contain any practical (i.e. 'hands-on') component and is often limited to a one-off basis with no follow-up to check whether the operators have adopted the technologies.

The operational effectiveness of the communal nursery group

Unlike the individual nursery sector in which the production inputs are generally provided by the operator, communal nurseries receive various forms of assistance because they have been established as part of development projects supported by a government agency, a non-government organisation or a foreign institution. The BBN for communal nursery effectiveness, presented in Fig. 5, shows that the availability of *project support* directly influences the *availability of germplasm*, *marketing assistance* and *training*, and most of all, availability of a satisfactory *production budget*. Despite the various forms of assistance, a low *operational effectiveness* (66%) is predicted for the baseline scenario.

Seedling quality greatly influences the probability of high *communal nursery effectiveness* (Table 5). Despite the relatively high seedling production budget in several communal nurseries (approximately 47% with a satisfactory budget), the germplasm used in seedling production is still mostly taken from unselected sources (approximately 81%), as is the case for individual nurseries. Although germplasm are mostly collected from unselected sources, many of these are of high physical quality (58.6%). However, despite 86% of the communal nursery managers having attended *training* classes provided by support agencies, the probability of lack of *technical skills* in high quality seedling production is remarkably high [p(inexpert) = 85.6%]. The lack of technical expertise results in a high chance of producing seedlings of low *physical quality* (approximately 69%).

The presence of *project support* greatly influences the *sustainability* of communal nursery operation. Withdrawing *project support* greatly reduces the likelihood of high *germplasm availability* (by 79.6%), cuts *seedling demand* by 28.7% and constrains the *production budget*. The high dependence of community organisations on *project support* increases the likelihood of low production *sustainability* when project assistance is finished. The probability of low *participation of members* when *project support* is over and the *production budget* is exhausted, is strikingly high, 84.6%. However, if revenue from seedlings is high, even with no continued funding, the participation remains at 60%. This illustrates that if community nurseries are to be sustainable after the withdrawal of donor support, then it is critical to develop markets for seedlings beyond those sales funded by the donor organisation. This market development should be a strategy incorporated into the operational plan of community nurseries and implemented well before support is withdrawn.

Table 5
Sensitivity of communal nursery effectiveness to seedling quality and production sustainability variables.

Node	Entropy reduction
Seedling quality	0.2379
Sustainability	0.1426

The operational effectiveness of the government nursery group

Seedling quality, *seedling production quantity* and *seedling uptake* are the key factors influencing the operational *effectiveness of the government nursery operation* (Fig. 6). Unlike smallholder nurseries, sustainability is not a determining factor on *government nursery effectiveness* because the operation of government nurseries is generally permanent. Instead, *seedling production quantity* and *seedling*

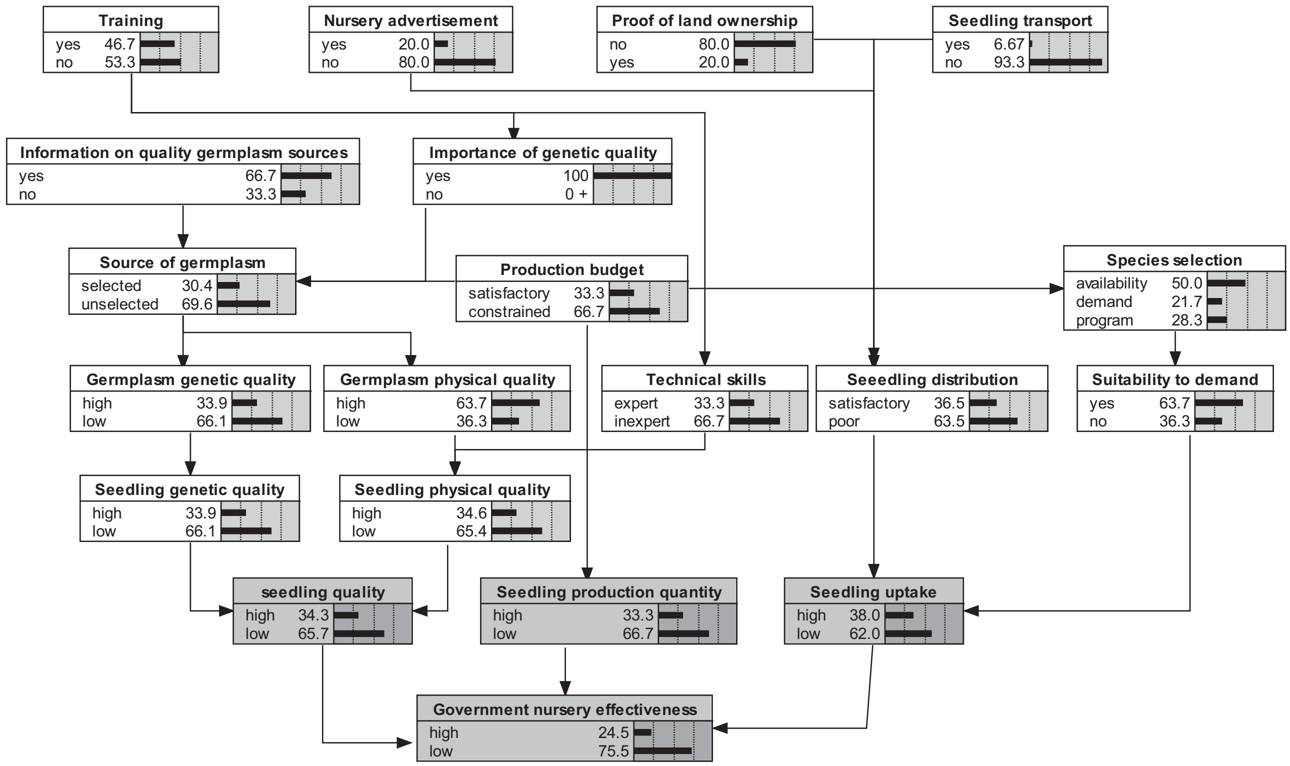


Fig. 6. The BBN for government nursery group indicating the factors that directly influence the operational effectiveness of government nurseries.

Table 6
Sensitivity of sources of germplasm in government nurseries to production budget and information on quality germplasm sources.

Node	Entropy reduction
Production budget	0.18114
Information on high quality germplasm sources	0.13788

uptake or seedling demand are important because government nurseries primarily function as sources of planting stock to tree farmers and other interest groups.

Overall, the *effectiveness of the government nursery operation* is low [p(low) = 75.5%)]. There is a prevalence of low *seedling quality* [p(low) = 65.7%)] and the likelihood of the smallholders' *uptake of seedlings* from government nurseries is also relatively low [p(low) = 62.0%].

Based on the survey data used to construct the BBN, there is a high probability that managers of government nurseries have *information on high quality germplasm sources* [p(yes) = 66.7%] and all are aware of the *importance of genetic quality* [p(yes) = 100%]. Although government nurseries generally have permanent funds to support nursery operations, the probability of sufficient funds to carry out effective nursery operations is low [p(constrained) = 66.7%]. For example, the sensitivity analysis presented in Table 6 suggests that although government nurseries will have direct access to high quality germplasm, a limited *production budget* will prevent the government nursery managers from using germplasm with high genetic quality. Hence, the probability of the government nursery sector producing seedlings of high genetic quality is relatively low (approximately 34%).

Government nurseries produce a considerable volume of seedlings in each production season. However, survey results show that the uptake of these seedlings by the smallholders is relatively low. Sensitivity analysis reveals that *seedling uptake* is largely influenced by the *seedling distribution* scheme (entropy reduction value of 0.19394 and 0.19010 for *seedling distribution* and *suitability to demand* nodes, respectively). Because government nurseries are situated in major towns and cities, the relatively affluent tree farmers almost always have the advantage of obtaining the free seedlings because they can afford to transport a large quantity of planting stock to their farms. This category of tree farmers is also the major buyer of seedlings in private nurseries.

Seedling distribution from the government nurseries is influenced by *nursery advertisement*, *proof of landownership* and *seedling transport*. Sensitivity analysis indicates that seedling transport has the greatest influence over *seedling distribution*. When transportation is provided, seedling distribution effectiveness increases from 36.5% in the baseline scenario to 60.8%. The sensitivity analysis also suggests that the requirement of *proof of landownership* has a greater influence on the effectiveness of *seedling distribution* than does *nursery advertisement*. Even if smallholders knew about the availability of free seedlings from the government nursery group, it is likely that the demand of seedlings would still be low if proof of landownership were required. Similarly, the model predicts that providing transportation will not maximise the effectiveness of seedling distribution if landownership remains as a requirement for obtaining seedlings. This implies that removing landownership, as a prerequisite for accessing seedlings from government nurseries would considerably improve the effectiveness of seedling distribution from government nurseries.

Policy implications

The simulation of the operation of the nursery sector in Leyte Province using the nursery operational effectiveness model reveals that the nursery sector is ineffective in providing a sustained supply of high quality planting stock of a wide variety of species to smallholder tree farmers. A number of key issues have contributed to this low operational effectiveness. These issues include the unorganised operation of the nursery groups that comprise the nursery sector, low access to high quality germplasm, lack of technical skills on nursery seedling culture, weak market for seedlings and poor flow of seedlings from the government nurseries to smallholder tree farmers.

The need for coordinated nursery sector operation

Good organisation of the private, communal ad government nursery groups is imperative to increase the operational effectiveness of the nursery sector. The nursery operational effectiveness BBN, however, indicates that in the baseline scenario, the operational scheme of the government and smallholder nursery groups are not well-coordinated. Given the potential complementarities among the three nursery groups, the coordination of the nursery operation can potentially improve the overall effectiveness of the forest nursery sector. Coordination requires appropriate planning of nursery objectives and implementing the nursery activities in such a way that there would be no conflict among the nursery groups. If funds allocated for seedling production in government nurseries decrease, then the operation of private nurseries is necessary to supply the planting stock requirement for smallholder forestry. Individual nurseries are highly accessible to smallholders because they are more numerous and widely distributed compared with government nurseries. Government nurseries are managed by technically trained managers who could potentially provide technical assistance to operators of private nurseries. Also, government nurseries in general have ready access to sources of genetically superior germplasm which most of the private nursery managers do not have.

Inasmuch as the simulation of the system using the nursery effectiveness model predicts that increased uptake of seedlings from the government nurseries would actually reduce the operational effectiveness of smallholder nurseries, it is necessary for the government nursery group to change its production pattern, and produce seedlings of species with limited supply of germplasm and difficult to propagate. This scheme will not preclude the sustainability of smallholder nurseries but rather promote their operation by avoiding their shortcomings.

Improving access to genetically superior germplasm

There is a need to promote the use of planting materials of high genetic quality in the individual and communal nursery groups. Providing an information and education campaign to convey to farmers the importance of genetically superior germplasm may increase the collection and use of high quality planting materials. Recognising the model prediction that merely educating farmers is unlikely to bring about a major improvement in the use of genetically superior planting stock, the provision of information regarding the sources and a steady supply of high quality germplasm are also essential.

Although it appears that government nurseries have funds for seedling production, the amount allocated does not meet the production cost of high genetic quality planting stock. With the available funds, using genetically superior germplasm means trading off seedling production quantity, which is not a preferred option given the quantity-oriented operation of government nurseries. As a supporting group in promoting smallholder forestry, there is a need for the government nurseries to focus on genetic quality of seedlings produced in order to demonstrate the benefit of using genetically superior germplasm to smallholders. Government nurseries can serve as a source of genetically superior germplasm as well as providing information on sources of genetically superior germplasm recognising that managers of government nurseries generally are aware of the importance of using germplasm of high genetic quality and have access to certified germplasm sources.

Capacity building to improve the technical skills of nursery operators in nursery seedling culture

Most of the seedlings sampled from the three nursery groups were of low physical quality, a reflection of the lack of skills of nursery managers in seedling production. Further, lack of knowledge on propagation techniques limits the variety of tree species available from most nurseries. Improving the quality of seedlings produced in the nurseries and increasing the diversity of seedlings available to smallholders therefore requires training of the nursery managers on appropriate nursery seedling culture.

While conducting training sessions is a common type of support provided to smallholders, operators of private nurseries have few opportunities to attend training events. Training activities are usually directed at organisations rather than individuals. Greater efforts to make training assistance available to individual nurseries is important given that individual nurseries dominate the nursery sector.

There is a need to assess and possibly revise the training provided by supporting agencies to ensure that farmers assimilate the information conveyed Instead of providing training as a one-off activity, it appears that there is a need to provide follow-up training to ensure that the smallholders are able to gain the knowledge, practice what they have learnt and improve their skills to become experts. There is also a need for supporting agencies to re-assess the delivery scheme of training and other capability-building measures that are extended to the smallholders.

The results of scenario tests suggest that part of the capacity building required is to improve the awareness of seedling producers on the benefits of using genetically superior germplasm. That awareness needs to be integrated with an information campaign to enhance the knowledge of tree farmers regarding the characteristics of high quality seedlings and their appreciation on the benefits of planting high quality seedlings. Although buyers generally assess the quality of seedlings during purchase, they usually rely on what is offered by nursery operators as high quality seedlings, which are relatively tall with a large number of fully developed green leaves. The base diameter and root system development, which are main indicators of seedling survival and growth in the field, are characteristics that are often neglected. Increasing the skills of seedling producers in producing high quality seedlings may not improve the use of high quality seedlings in reforestation and tree farming endeavours unless the project implementers and tree farmers also recognise the importance of planting high quality seedlings and use this as a basis for their purchase decisions.

Improving the financial viability of the nursery business

Analysis using the nursery effectiveness BBN indicates that in order to improve the operational effectiveness of the private nursery sector, there is a need to improve seedling sales by increasing market demand. It is imperative to include marketing assistance as a component of the support provided to smallholder nursery operators. Support could be in the form of advertising of smallholder nurseries by establishing networks with potential seedling buyers or widening the network of potential buyers to sustain sales. Being recognised by potential customers, government nurseries could play an important role in providing this support to the private nurseries.

Understanding the interaction between markets of germplasm and seedlings is also important in improving the financial viability of the nursery enterprise. Recognising that seedling availability is a function of germplasm supply, it is necessary to analyse the market structure and supply chain of germplasm. Further, it is important to understand the germplasm handling requirements of tree species. The government nursery managers could play an important role to help the private and communal nursery operators, especially in relation to seeds of recalcitrant species that do not store well and with vegetatively propagated clonal selections associated with active 'tree domestication' (see Carandang et al., 2006 and Roshetko and Dianarto, 2008 for further discussion).

Enhancing the flow of seedlings from government nurseries to smallholder tree farmers

The operational effectiveness of government nurseries is reduced by the low demand for seedlings. The current scenario suggests that seedling uptake from government nurseries is largely hampered by poor seedling distribution and partly influenced by the suitability of species raised relative to the demand of the smallholders. Improving the effectiveness of the government nursery operation obviously means increasing seedling demand and this could be achieved by improving seedling distribution together with aligning species selection to the demand of smallholders.

Considering that government nurseries are located far from villages involved in reforestation projects, one possible means of improving the uptake of seedlings from government nurseries is to distribute seeds in packs or young seedlings in boxes rather than seedlings in pots. This distribution system was used in India (FAO, 1985) and Kenya (Shanks et al., 1994) to reach remote villages with planting materials from the forestry department.

Removing the requirements imposed by government nurseries to prove land ownership and provide maps of the area to be planted when requesting seedlings is one intervention that is likely to improve seedling uptake from government nurseries. These requirements are impediments to smallholders in accessing seedlings.

Analyses with the BBN model suggested that improving the flow of seedlings from government nurseries would have a negative impact on the sustainability of private nurseries due to duplication of most species raised. In spite of the access of government nurseries to germplasm sources of a much broader range of species compared to smallholder and community nurseries, and their relative expertise on seedling production, species selection is usually determined by those species with abundant supply of germplasm. These species are also the species mostly propagated by smallholder nursery operators and thus government nurseries are often in direct competition. To prevent competition with smallholder and community nurseries, species selection for government nurseries needs to be based on those species that cannot be propagated by smallholders due to their lack of technical knowledge of seedling culture and lack of germplasm.

Summary and concluding comments

The modelling exercise undertaken in this research highlights the large number of barriers to an efficient nursery sector in Leyte Province. The availability of germplasm has the greatest impact on the sustainability of nursery operations, particularly those that are managed by smallholders. There is a need to focus on supporting the smallholder nursery sector by providing a sustained supply of germplasm. Improving the availability of germplasm does not only mean increasing the quantity of supply but also the quality. While the cost of certified germplasm may be high, the model suggests that there is a greater chance for smallholders accessing high quality germplasm if they have information regarding the potential sources rather than having no knowledge at all.

The sustainability of the operation of communal nurseries is greatly influenced by the presence of project support. The model simulations predict that where funding from external agencies is absent, there is little chance that the nursery will sustain its operation because participation of community members declines. Sustaining the operation of community nurseries therefore requires constant financial resources and this is where seedling sales can potentially serve an alternative income source to the community. Improving seedling sales of communal nurseries through improved marketing offers a buffer against the negative impact of the cessation of project funding. Linking the nurseries to a wide population of potential seedling buyers is a vital part of interventions for improving the operational effectiveness of communal nurseries.

Government nurseries can play a crucial role in improving the effectiveness by diversifying their production to focus on species that are in demand by smallholder farmers and which cannot be supplied by individual or communal nurseries. Failing to do this will result in the current situation continuing where the government nursery sector competes with private and communal nurseries, which ultimately reduces the effectiveness of the entire nursery sector. The government nursery group can also serve as conduit for improving the supply of high quality seeds to smallholder nurseries, distributing information and extension materials and providing technical support. In addition, it is important for government nurseries to focus on producing high quality seedlings rather than large volumes of seedlings simply to meet production targets and demand.

Improving the operational effectiveness of the forest nursery sector is imperative to improving the supply of high quality seedlings for reforestation programmes in the Philippines. While the people-based forestry approach of forest management promotes the operation of private and communal nurseries, the government nurseries also have a significant role in providing planting stock for reforestation programmes in the country. Recognising the strengths and weaknesses specific to each of these three nursery groups, a systems approach is necessary to organise the operation of these nurseries and establish a sustainable supply of high quality seedlings.

Appendix A.

Variables (nodes), states and information used to complete CPTs in the nursery effectiveness BBN.

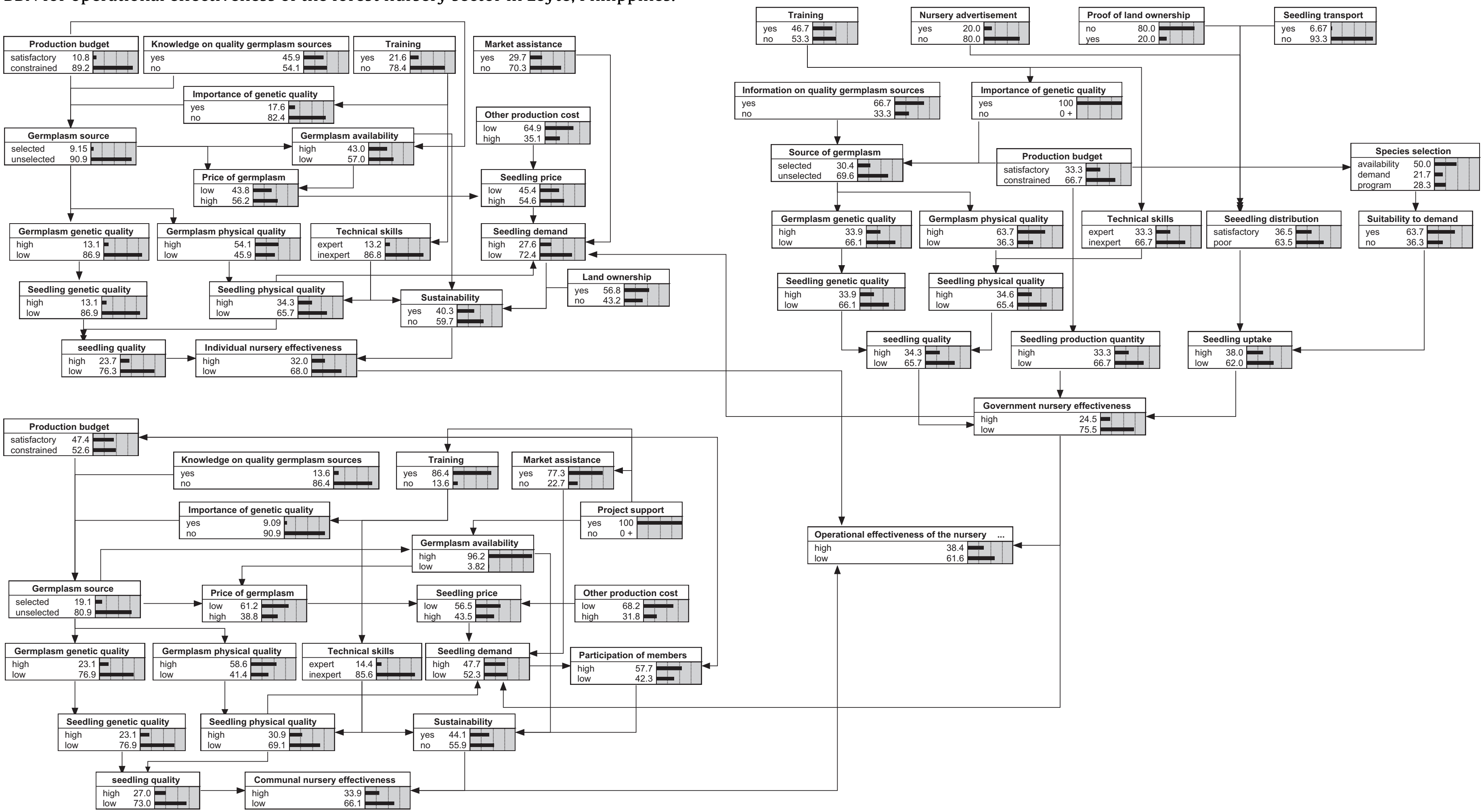
Variable/node	Definition	States	Information type [a]	Data sources
A. Individual nursery				
Individual nursery effectiveness	Ability of the nursery to produce genetically and physically high quality planting stock from diverse species of trees at any time when the need for planting stock arises	High, low	Type 2	Stakeholder elicitation through FGD
Seedling quality	Pertains to genetic and physical qualities of seedlings	High, low	Type 4	Best judgement; expert opinion
Seedling genetic quality	Refers to the genetic background of the seedling	High, low	Type 4	Best judgement; expert opinion
Seedling physical quality	Totality of the physical characteristics of seedlings particularly health, robustness and root form	High, low	Type 2	Stakeholder elicitation through FGD
Sustainability	Pertains to the ability of the nursery operator to continue production at any time when the need for planting stock arises	Yes, no	Type 2	Stakeholder elicitation through FGD

Variable/node	Definition	States	Information type [a]	Data sources
Landownership	Indicates whether the nursery operator owns a parcel of land	Yes, no	Type 1	Interviews
Germplasm genetic quality	Refers to the genetic make-up of the germplasm used in seedling production	High, low	Type 4	Best judgement; expert opinion
Germplasm physical quality	The outward quality of the germplasm including health and vigour	High, low	Type 2	Stakeholder elicitation through FGD
Technical skills	Indicates knowledge and skills of the nursery operator in carrying out nursery activities	Expert, inexpert	Type 1	Interviews
Seedling demand	This refers to the uptake of seedlings in the nursery	High, low	Type 4	Best judgement; expert opinion
Price of germplasm	This refers to the anticipated germplasm value rather than the specific monetary equivalent of germplasm	Low, high	Type 2	Stakeholder elicitation through FGD
Seedling price	This refers to the anticipated value of seedlings rather than the specific monetary equivalent of the seedling	Low, high	Type 2	Stakeholder elicitation through FGD
Germplasm source	Corresponds to the origin of germplasm i.e. whether it was taken from a selected source	Selected, unselected	Type 1	Interviews
Germplasm availability	This relates to the physical quantity of germplasm	High, low	Type 2	Stakeholder elicitation through FGD
Other production cost	This collectively refers to costs incurred in seedling production other than the cost of germplasm including cost of labour, transportation during germplasm collection and nursery materials	Low, high	Type 1	Interviews
Importance of genetic quality	This refers to the relevant knowledge of the operators regarding the benefit of using germplasm of high genetic quality	Yes, no	Type 1	Interviews
Production budget	As used in the model, this variable refers to the perception of the nursery operators towards the financial resources allotted for seedling production	Satisfactory, constrained	Type 1	Interviews
Knowledge of quality germplasm sources	This corresponds to the relative level of information of operators regarding the sources of high quality germplasm	Yes, no	Type 1	Interviews
Training	This variable denotes the attendance by operators of training activities conducted by supporting agencies	Yes, no	Type 1	Interviews
Market assistance	This denotes the support extended by assisting agencies to facilitate the marketing of planting stock	Yes, no	Type 1	Interviews
B. Communal Nursery				
Communal nursery effectiveness	The operational effectiveness of a communal nursery operation denotes the ability of the nursery to produce genetically and physically high quality planting stock from diverse species of trees any time when the demand for planting stock arises	High, low	Type 4	Best judgement; expert opinion
Participation of members	The continuous involvement of members in the nursery operation activities of the organisation	High, low	Type 2	Stakeholder elicitation through FGD
Project support	The assistance given to the organisation usually in the form of marketing assistance, provision of germplasm, training activities and financial support	Yes, no	Type 1	Interviews
C. Government nursery				
Government nursery effectiveness	The operation of the government nursery group is considered effective if the volume of seedling production per growing season is high, the seedlings produced are of high genetic and physical qualities and the uptake of seedlings by smallholders from the government nursery is high	High, low	Type 4	Best judgement; expert opinion
Seedling production quantity	This variable corresponds to the volume of seedlings produced per year in the government nursery group	High, low	Type 2	Stakeholder elicitation through FGD
Seedling uptake	This pertains to the volume of seedlings in government nurseries that were distributed or utilised by intended end-users, particularly the smallholders	High, low	Type 4	Best judgement; expert opinion
Seedling distribution	This is a variable describing the status of seedling distribution in government nurseries, whether the distribution of seedling to smallholders is satisfactory or poor	Satisfactory, poor	Type 4	Best judgement; expert opinion
Suitability to demand	This variable corresponds to the compatibility of the species raised in government nurseries to the demand of smallholders	Yes, no	Type 4	Best judgement; expert opinion
Species selection	This variable refers to the considerations in government nurseries on the selection of species to raise	Availability, demand, programme	Type 1	Interviews
Nursery advertisement	This variable describes whether the government nurseries have made sufficient effort to make their existence and the type of support that they could extend known to smallholders	Yes, no	Type 1	Interviews
Proof of landownership	Documents required from smallholders when requesting seedlings to prove their ownership of the land where they plant the seedlings	Yes, no	Type 1	Interviews
Seedling transport	This refers to whether the government nurseries have provided transport facilities to deliver the seedlings from government nurseries to the communities	Yes, no	Type 1	Interviews
D. Overall nursery sector				
Operational effectiveness of the nursery sector	This refers to the ability of the nursery sector to support the seedling demand of the smallholder forestry group by producing high quality seedlings of diverse species at the appropriate time	High, low	Type 2	Stakeholder elicitation through FGD

[a] Information Type 1: raw data collected by direct measurement (i.e. survey data or records); Information Type 2: raw data collected through stakeholder elicitation; Information Type 3: output from process-based models calibrated using raw data collected by direct measurement; Information Type 4: academic 'expert' opinion based on theoretical calculation or best judgement.

Appendix B.

BBN for operational effectiveness of the forest nursery sector in Leyte, Philippines.



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