Helping farmers select forage species in Central America: the case for a decision support system

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Abstract

Intensification is a key strategy for smallholder farmers in Central America, and improved forages can play a significant role. To facilitate adoption of forages a spatial decision support system (SDSS) is under development to target forage species to particular biophysical, socio-economic and management niches. This paper discusses the role of improved forages in smallholder systems, and the potential for a SDSS to provide information and recommendations to farmers and their advisors. The potential pitfalls of designing and implementing a SDSS for developing world agriculture are discussed and addressed, and the SDSS under development is described.

Keywords: SDSS, tropical agriculture, Central America, improved forages

Introduction

In order to alleviate poverty and improve food and income security in the developing world, sustainable production systems are necessary, balancing environmental protection with social and economic sustainability. Intensification of production may be the only solution for resource-poor farmers (Peters et al, 2001).

Improved forages can have an important function in intensification. Forages play a central role in what Delgado et al (1999) term the Livestock Revolution, led by increasing worldwide demand for livestock products. They contend that in the next 20 years, cattle and other livestock will play an increasingly important role in agriculture, particularly in developing countries.

Decision support systems are increasingly being used in agricultural systems. Most of these tools are aimed at large-scale farmers in the developed world, often requiring large amounts of input data. However we suggest that a decision support system has potential to aid decision makers in the developing world, even in data sparse environments.

This paper describes the role of forages in smallholder farming systems and examines how a decision support system might be developed to aid in the selection of forage species, utilizing Central America as a case study. Finally an outline is presented of a decision support system that is being developed for this purpose.

Forages in smallholder farming systems, with emphasis on Central America

Central America has 93.5 million ha of grazing land, supporting 41.4 million head of cattle (FAO, 2002). It is estimated that in tropical America, 90% of grazing lands are still in native pastures. The definition of smallholder farmer varies from country to country, and in Central America may be defined as a farmer with around 10 cows (Staal, 2003). Poor livestock keepers form an extremely diverse group. Attempts to categorise poor livestock keepers by the number of animals owned may therefore be misleading (Chipeta et al, 2003). An indication of the percentage of smallholder farmers can be derived from the percentage of rural population below the poverty line, which in Central America ranges from 41% (Costa Rica) to 76% (Nicaragua) (World Development Report 2000/2001, cited in Thornton et al, 2002). This translates to just under half of Central America's rural population of 43.4 million (2001 estimate (FAO, 2002)) living below the poverty line. It can be expected that the majority of smallholder farmers will belong to this group.

The primary use of forages is as animal feed, however they can also be used for such diverse purposes as human nutrition, and natural resource management. The selective introduction of forages into smallholder farming systems can help reduce soil erosion, and aid sustainable intensification by regenerating degraded soils and replenishing nitrogen through N-fixation. In addition they can help control weeds, allow the farmer to be less dependent on external inputs, and are suited to diverse production systems (Humphries, 1994, Schultze-Kraft and Peters, 1997).

In the tropics, and in particular in Central America, the adoption of improved forages, in particular legumes, has been low (Peters et al, 2001). Stür et al (2002) and Peters et al (2001) identify some reasons for limited and slow adoption of forages. These include unfamiliarity with the technology, the fact that longer-term benefits may not be immediately obvious, unavailability of planting material, unfavorable policies, and lack of participation of farmers in research and development. Adoption may also be limited by restrictions imposed by climate, soil and other biophysical factors. In addition cultural traditions and preferences may also play a role. Farmers may be risk-averse for a number of reasons, and uncertainty surrounding the likelihood of a new species being successful will also be a factor.

Often farmers and extension workers are aware of constraints and opportunities in their production system, but have limited access to information on potential solutions. This is particularly true as the poverty level increases and in environments far away from institutional support. In such a situation adoption of a new technology may be facilitated when an expert is called upon to recommend a forage species. In a typical case a farmer or their advisor will contact an extension worker, a seed provider or an institution knowledgeable in forage technology with a request for a forage recommendation. The expert will attempt to firstly identify constraints and problems in the whole farming system to see where there is a need for forages. For example issues with production levels, erosion or degradation may all call for a different approach. Once the need is identified the niche is then considered. The niche can be described in both biophysical and socio-economic terms. For example, the niche may be constrained by climate and soils, and also by the current cropping system, farmer resources and management practices. Adoption may also occur when seed becomes available or is promoted, and when neighbors adopt. However, in many cases such experts may be scarce and hence not be easily accessible, in particular in remote rural areas.

To illustrate the decision process involved in the selection of forages, we describe two typical smallholder farmers in Central America. The first, Juan Gea López, lives near Esquipulas in the central region of Nicaragua (Figure 1). Twenty years ago he owned one cow and seven hectares of native pasture. Over time he sold his beat-up old truck, bought more land, and built a house. Now he owns 59 hectares and 172 head of cattle (of which about 50 are direct descendants of his original cow), and a nice new four wheel drive. He milks 24 cows, producing on average 8.7 liters/cow a day, in a region where the average is as low as 2.4 liters.is 5.4 liters. He has an artificial insemination program, sells a number of cattle each year, and provides the equivalent of 5 permanent farm hand positions. He has put his three children through university. He is considering moving to two milkings a day, but at this stage cannot justify the cost of mechanized milking, irrigation, or electric fences.

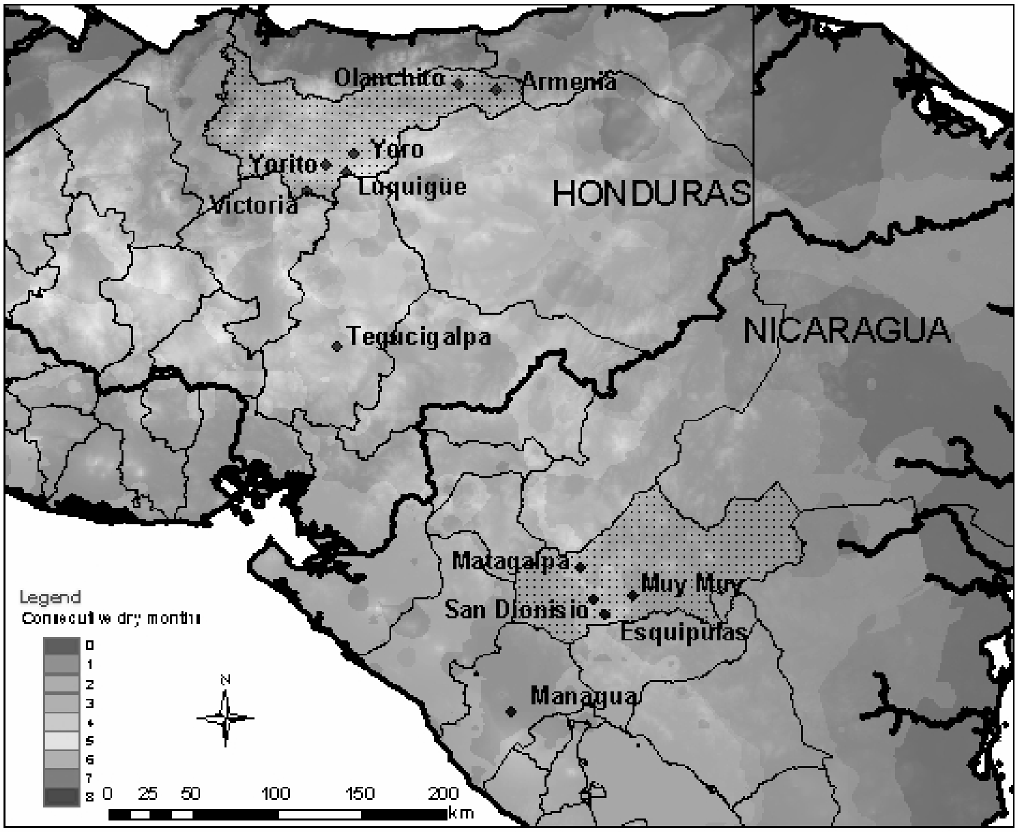

Figure 1. Matagalpa department, Nicaragua and Yoro department, Honduras.

His farm is situated in a part of the country where the dry season lasts six or seven months and Hurricane Mitch destroyed a couple of hectares of his land in 1998. Gea has created a thriving business where other more traditional farmers have failed, through good management, careful research and by chasing opportunities. During the 1980s, when monetary assistance was by preference given to cooperatives, he struggled as an independent farmer to gain access to loans and technical assistance. He slowly but surely increased his land and his stock, along the way experimenting with cattle breeds and fodder crops. He planted Taiwan (*Pennisetum purpureum)*, King Grass (*Pennisetum* *purpureum* x *Pennisetum typhoides* hybrid) and sugar cane (*Sacharum officinarum)*, but decided the work required to process these for cattle fodder could not be justified. In 1993 he was offered Brachiaria brizantha seeds, an improved forage pasture introduced by CIAT (International Center for Tropical Agriculture) into Central America. He planted just a little in places where other pastures were failing, gradually increasing to seven hectares of Brachiaria brizantha mixed with Arachis pintoi, a variety of peanut providing quality protein, also introduced by CIAT. The cattle graze the pastures in the wet season and are given hay cut from the pastures in the dry season, supplemented with his own concentrate of chicken manure, Mucuna pruriens and mineral salt mixtures.

Although Gea's success can mostly be attributed to good management practices and a willingness to experiment, the introduction of improved forages into his pastures played an important role in increasing both milk production and milk quality. He is planning on planting a larger area in improved forages, and would like to know if there are other species better adapted to the climate and soil conditions of his farm, which can be used for both grazing and hay. Without ready access to expert opinion he is unlikely to find out about potentially excellent options for his situation, which could greatly increase his return on investment.

Tomas Banegas Rosales also lives in a region of Central America with a long dry season. His 8.5 ha of pasture and forest, maize and coffee lie in Luquigüe, in the Yoro district of Honduras (Figure 1). He had four cows but had to sell them when the coffee price dropped in 2001, to pay for his children's primary education. Five of his adult children work on the farm. He would like to buy cows again to provide milk for household consumption, but cannot really see the point of investing in improved forages when he has no cows to feed. If he knew for certain he would have enough money to buy cattle later in the year, then he would consider planting forage in preparation.

Gea and Banegas's situations are vastly different, yet they share the challenge of making a living from the land in the dry region of Central America. Within the region some farmers have twice daily mechanized milking, irrigation, a large area of improved forages, and silage and hay production for the dry season. Others milk two cows by hand for only part of the year, producing a couple of liters of milk for household consumption. Some drive their cattle large distances to reach higher, slightly greener pastures in the dry season; others build a second milking shed to save the cows a walk of 1 km. One farmer in near Victoria in Yoro, Honduras, trained as a vet, has a lot of experience and good land near a river. Yet he receives a low price for his milk, therefore lacking incentive and means to make improvements. In a pattern common to the region, this means he continues to milk by hand and graze his cattle on native pastures, which in turn means the quality and quantity of milk remain the same. Therefore his income remains unchanged, even though a small investment in improved forages, matched to his unique situation, could make the difference. He is intelligent and knowledgeable, what is lacking is confidence that investment in improved forages will pay off.

This lack of confidence is often warranted in Central America, where improved forage species can be selected based on seed availability or on latest releases, often disregarding climatic and other pertinent factors. For example in Armenia and La Ceiba in the humid Atlantic region of Honduras, pastures such as *Brachiaria brizantha,* which are known to do well throughout Central America, are considered poor quality because of problems with waterlogging.

A large number of improved tropical forage species exist which are well suited to Central American conditions. CIAT and its partners have tested these species, evaluating adaptability, establishment and production in various locations throughout Central America. One such location is at Las Minas, a few kilometers from Luquigüe, Honduras. If Banegas decides he wants to try a forage species, he could visit this site and see for himself how well these forages grow under conditions in the immediate vicinity of his farm. He can evaluate the different possible uses of grasses, legumes and shrubs, and he can receive technical advice on sowing and management practices.

The closest trial site to Gea is about 20km away in San Dionisio. Within this distance there is already variation in elevation, soils and rainfall patterns. Other farmers live a great deal further from forage trial sites, making it difficult for them to benefit from this research. Although CIAT has compiled a comprehensive database with data from the trial sites (Barco et al, 2002), it is not an easy task to translate the results to other locations.

If the available data and knowledge could be made accessible and relevant to these farmers' unique situations, then they could use this information to make better informed decisions on which forage species to try, based on local climate and soil conditions, and taking management requirements into account. A decision support system is a viable way of meeting this goal, and we will examine what is needed to create a good decision support system for this purpose.

Decision support systems in agriculture

The purpose of a decision support system (DSS) is to provide data, procedures and analytical capability leading to better-informed decisions. Typically a DSS consists therefore of data, a rule-base, algorithms for combining these, and a user interface. A DSS is not necessarily computer-based, but in this discussion we will assume a DSS is implemented in a personal computer environment.

Agricultural DSS have been in existence since at least the mid 1970s (e.g. SIRATAC, a cotton production decision system, and EPIPRE, a European wheat DSS, were both begun in 1976 (McCown et al, 2002)). For farmers in the developed world, there are hundreds of decision support systems available, covering production decisions relating to crops such as cotton, wheat and pasture (McCown et al, 2002).

A body of research is emerging on the "crisis" of DSS research in agriculture, that is, DSS use in agriculture is declining and not living up to its apparent early promise (see for example McCown et al, 2002, Walker, 2002 and Cox, 1996). The journal Agricultural Systems devoted a special issue (Issue 74, 2002) to reviewing the low adoption and frequent abandonment of DSS by farmers.

Barriers identified in the adoption of agricultural DSS in the developed world include complex design and presentation of DSS, unrealistic requirements for monitoring data, and the need for the farmer to own a computer (Cox, 1996). Walker (2002) adds irrelevance and inflexibility of many DSS, lack of user confidence and institutional and political barriers, among others.

Less research has been done on the adoption of agricultural DSS in the developing world, but it can be expected that issues related to data requirements and computer ownership would be intensified. Hall et al (1997) researched the implementation of GIS (Geographical Information System)-based DSS for facility planning in developing countries and found barriers including inadequate computing skills, poor computing facilities and poor data availability and quality. The same barriers would presumably exist for agricultural DSS adoption in developing countries.

The development of a DSS therefore requires more than just the implementation of the DSS itself. Walker (2002) lists six essential steps, starting with needs analysis, followed by design and implementation. Development often stops after implementation, and as Cox (1996) points out there is poor understanding among researchers of what an agricultural DSS does when farmers or other practitioners use it. Walker's final three steps are capacity building, fostering uptake and monitoring and evaluation. Cox (1996) also argues that for a DSS to be successful, it needs to be embedded in a wider social process.

A spatially enabled DSS has a spatial component, in the form of spatial input data, spatial analysis capabilities, and / or spatial output. The spatial component is usually implemented using GIS technology. A large number of GIS-DSS exists within agriculture (see for example Berger 2001, Booth 1995, Hill 2000), and even more in wider fields that could be applied to agricultural decisions. As GIS data becomes more available and reliable in the developing world, GIS-DSS are emerging specifically targeted to these environments, with encouraging results. Crossland et al (1995) found unequivocal evidence that addition of GIS technology to the decision environment for a spatially referenced decision task reduced the decision time and increased the accuracy of individual decision-makers. Staal et al (2002) found that the inclusion of GIS-derived variables and spatial analysis improved their models of technology uptake on smallholder dairy farms in Kenya. However Hall et al (1997) found that although in some developing countries (e.g. Chile and Costa Rica) GIS infrastructure is in place, expertise has not yet evolved to the point where practitioners have been able to develop their own DSS.

The case for a decision support tool for selecting forage species

The process in selecting forage species consists of a series of decisions (Figure 2), firstly deciding whether change is needed, if so, what type of change, and if that type of change is to plant a forage species, then which one.

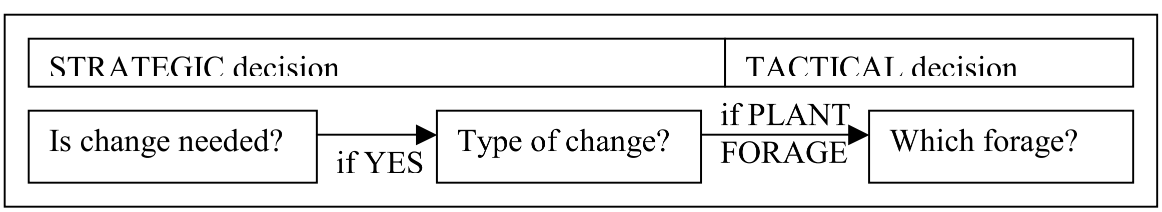

Figure 2.Decision process for selecting a forage species

At the strategic level, the decision on whether or not to plant an improved forage species depends on whether or not a need for change is identified, and if so, what type of change. This could be a number of options, one of which might be the decision to plant an improved forage. This decision will depend on a number of management and socio-economic factors including current crops, current management practices, number and type of animals, land available, economic resources, market distance and type, risk averseness, labor available, experience, education, access to extension and other socio-economic factors, as well as biophysical factors. Staal et al (2002) found in the decision of Napier grass uptake in Kenya that level of education, access to formal milk outlets, rainfall, temperature and market access were particularly significant.

The importance of socio-economic factors becomes evident when talking to farmers in Central America. Common reasons for not expanding the area planted in improved forages include cost of labor, availability of labor, cost of seed, availability of seed, and increased workload in improved forage management. Also in mixed systems cattle are often seen as low priority, and any investment will be put into crops.

At the tactical level the decision is which improved forage species to select, and assumes the strategic decision has already been made. This decision depends mostly on biophysical factors and management practices. However some socio-economic factors may still be important at this level of decision-making, in particular risk-averseness.

The decision support system described below addresses the decision at the tactical level, assuming that an improved forage species is required, and the problem is to select which one(s). As reported above, barriers to adoption of forages include unfamiliarity, lack of understanding of longer-term benefits, biophysical limitations and possibly cultural and social limitations. A DSS can address these barriers firstly by making information available to farmers (increasing familiarity and describing long-term benefits), and secondly by matching forage species to unique biophysical and socio-economic niches.

We aim to address the obstacles cited above impeding adoption of agricultural DSS. One of the most obvious barriers is the need for farmers to own a computer. The UN reports computer ownership in Central America ranging from 0.96 (Nicaragua) to 17.02 (Costa Rica) per 100 population for 2001 (UN, 2003), with the proportion in rural areas expected to be much lower. Our proposed solution is to aim the DSS not at the farmers themselves, but at their advisors, including extension workers and NGOs. Farmers' inadequate computer skills can also be overcome by using the extension worker as an intermediary. An additional possibility is to make the DSS available at local telecenters, where they exist, for computer-literate farmers. This model of dissemination may also help counter the problem of the tool becoming redundant once a farmer has used it once, as one instance of the tool can be used to assist many farmers over a region.

Other obstacles cited are poor data availability and quality, and unrealistic requirements for monitoring data. While there is certainly less spatial data available in the developing world than in the developed world, there is enough basic data available in most regions for biophysical factors such as climate, as well as socio-economic and agricultural indicators from censuses. Currency and accuracy of these data is always an issue that must be acknowledged and addressed. Additional data needs to be gathered from the farmer but this need not be in the form of intensive monitoring. Smallholder farmers can be expected to know and report factors such as soil fertility or waterlogging problems on their land.

The remaining issues of complex design and presentation, irrelevance, inflexibility and lack of user confidence need to be addressed in the needs analysis and design phases of the project. These are discussed below in relation to the SDSS currently under development. One obvious design criteria is that the tool needs to be available in Spanish for users in Latin America, as well as in English and potentially French (if the tool is expanded to Africa).

DSS development steps

Needs analysis

The need for a DSS to target crops in the developing world was perceived by the forages group at CIAT, who saw the potential for a spatial DSS to target improved forage species to specific niches. In 2000 a number of individuals at national agricultural ministries, NGOs and research organizations were canvassed on their opinion regarding the proposed DSS. Some voiced doubts based around the obstacles outlined above, but most were supportive and expressed an interest in the product. In addition the authors' research involving forage crops in Central America has highlighted for them the potential of such a tool.

Design

The design of the tool has been based on research on related initiatives, both in forages and spatial modeling, and through feedback from potential users of the tool. The engine of the tool is Bayesian probability modeling, with parameters derived from data and from expert knowledge. The guiding principles for the design stage include ease of use, flexibility and transparency. It should be clear to the user where the data come from and how accurate these data are, so that the user can have confidence in the recommendations of the tool. Bayesian modeling has been selected partly because of the transparency of the method, and also because the method deals well with both uncertainty and expert knowledge. The tool also needs to be flexible enough so that it is accessible and useful to farmers and scientists alike.

The DSS design includes five modules: selecting suitable species for a location; selecting suitable locations for a species; updating species data; adding new species data; and a tutorial. The first two modules are for all users, with the first especially envisaged for farmers and their advisors. Updating and adding species data provides the input data for the first two modules, and should be used by tropical forage experts. The tutorial will be targeted to all levels of users.

In the first module, the user is initially prompted to define a location of interest. This might be a particular point location, representing a field or a farm, or a wider area, representing for example an extension worker's region. Once the location is defined, biophysical, socio-economic and management factors are defined. Many of the biophysical factors are derived from GIS data, in particular climate and elevation. While GIS data does exist for soils, it is generally not detailed enough for the present analysis. Therefore in the current implementation the user is asked to provide local soil details. The possibility exists to incorporate GIS soil maps should they become available. The user is also required to input management requirements, including the intended use of the forage. In addition any special considerations should be indicated, such as waterlogging, salinity or frost. A final input requirement from the user is the farmer's level of risk tolerance, that is, to what level is the farmer able or willing to take risks. This is a relatively straightforward exercise, with a choice between high, medium and low risk averseness, and can be subjectively assessed by the user of the tool in conjunction with the farmer. This impacts on whether species will be suggested which may be appropriate but about which little is known (Figure 3).

The next step produces results based on the factors given and probability data stored in the tool's database. A number of suitable forage species will be recommended, ranked by probability of suitability for the given conditions (Figure 4). Two additional measures are shown: certainty gives an indication of how much is known about the species under these conditions, based either on a combination of number of trial sites and expert knowledge. Sensitivity reflects how narrow the band of suitability is, i.e. whether a small change in factors triggers a large change in suitability or not. The user can query each recommendation for more information.

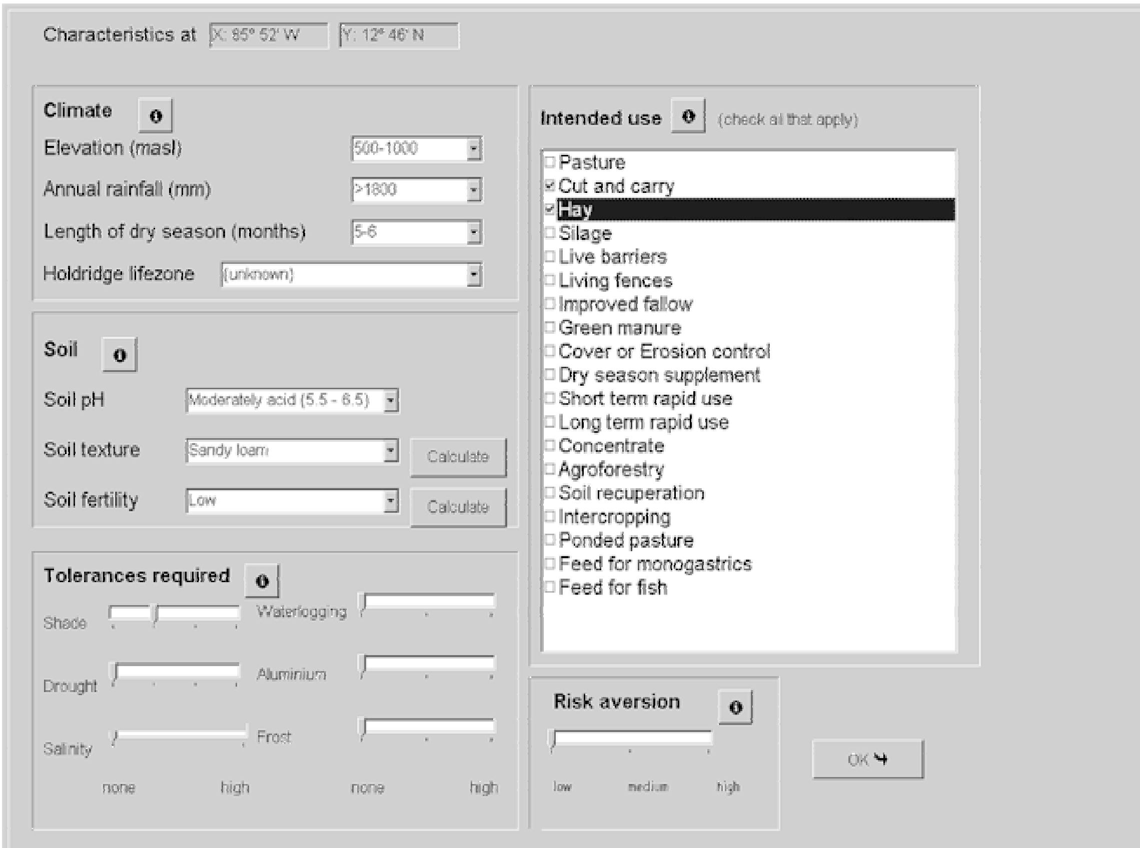

Figure 3. Location factors

Figure 4. Results

For each species a probability map can be displayed, showing how the different factors impact on the suitability of the species in each location. (Figure 5). The maps are dynamic, and are produced on each run depending on the factors selected for inclusion. If species data has been updated then this will also be reflected in the maps. The map is also examinable, with descriptions of factors and results available for a location by pointing and clicking with the mouse.

Graphs are also available for each species, summarizing the effects of each factor on suitability (Figure 6). The joint probabilities are in essence multi-dimensional – the graph can only display one dimension at a time. However by clicking on the graph the user can drill down through the dimensions.

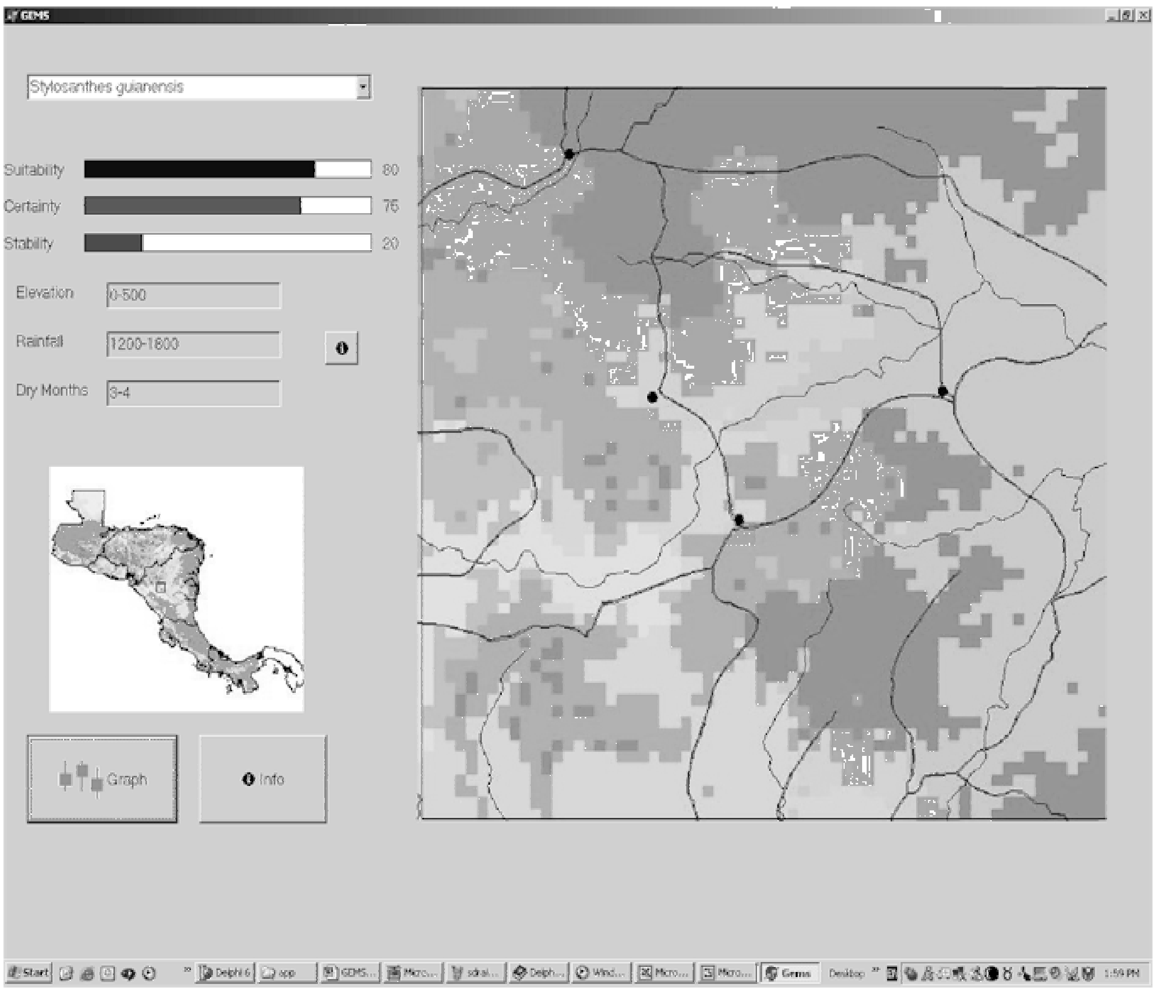

Figure 5. Joint probability map

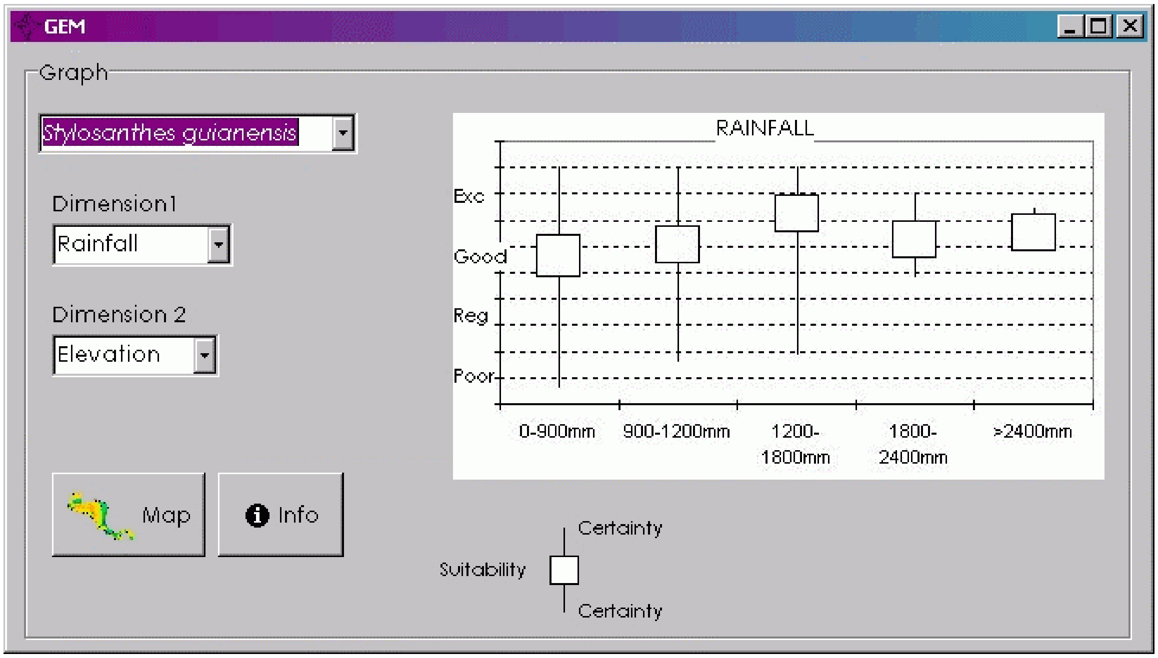

Figure 6. Suitability graph

The second module (Figure 7) works in a similar way, however a species is identified up front with maps produced for the area of interest based on GIS data only.

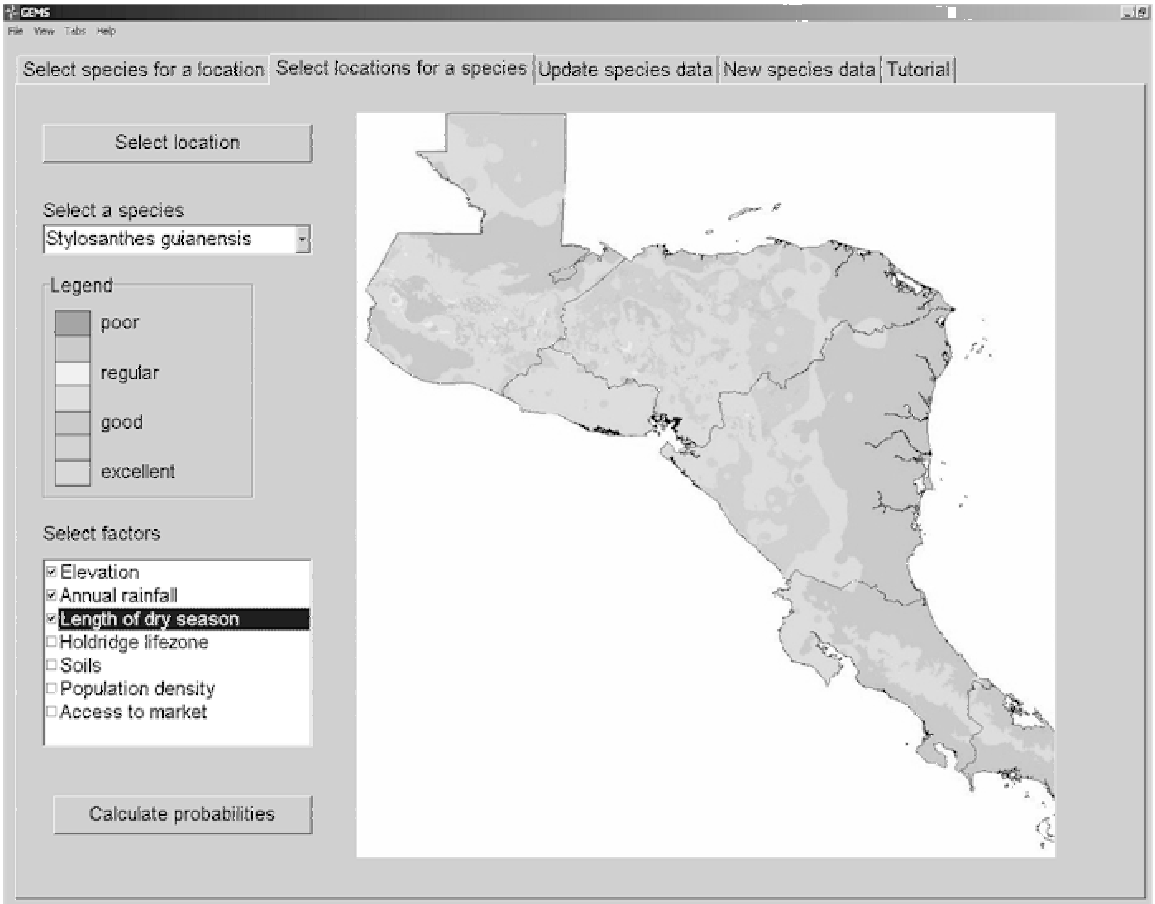

Figure 7. Selecting suitable locations for a species

The modules for updating and adding species data use databases such as the CIAT RIEPT (Red Internacional de Evaluación de Pastos Tropicales – International Network for Evaluation of Tropical Pastures) (Barco et al., 2002) database and – in the future –SoFT (Selection of Forages for the Tropics) and expert knowledge. The user selects one species and one factor at a time, and examines, updates or creates a probability matrix for the level of adaptation of the species in each factor category (Figure 8). Dynamic maps can be examined and the probability matrix adjusted until the expert is satisfied. Once probability matrices for all factors for a species have been defined, their joint probabilities can be calculated and examined. Dynamic maps of joint probability (for GIS based factors) can also be examined, similar to that shown in Figure 5.

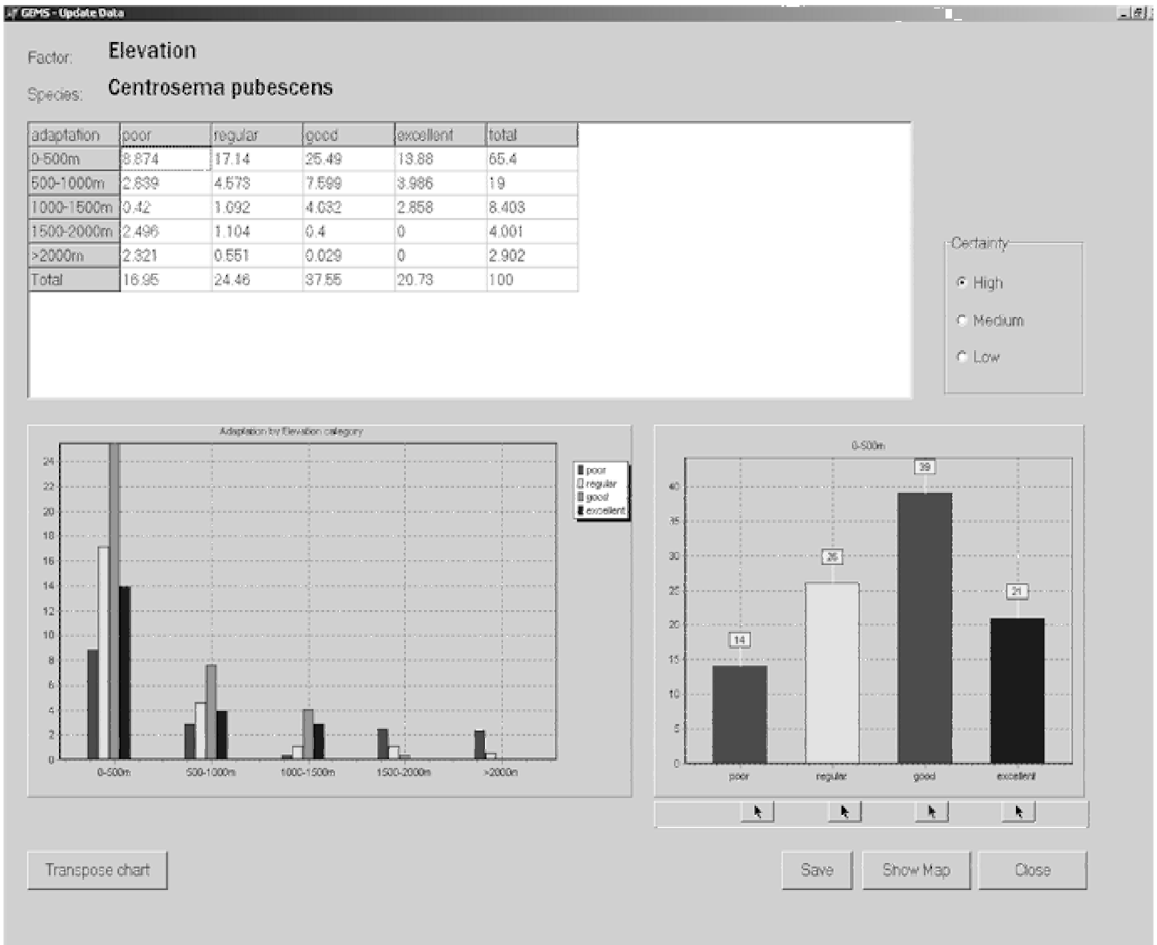

Figure 8. Defining conditional probabilities

The tutorial module runs through examples for each of the previous four modules, focusing on typical environments for smallholder farmers in Central America, such as Gea and Banega.

Implementation

The DSS is being implemented using Borland Delphi 6 (Borland Software Corporation, 2002) and ESRI MapObjects LT (ESRI, 2000). This means that the user does not need to own a proprietary GIS package in order to run the application. In addition data is stored, where possible, in plain text format (xml format for public data, encoded for non-public data) to avoid the necessity for a database engine or database applications such as MS Access. This means that the tool is available for use on any computer with a CD-ROM or internet access, with enough disk space, but that no other programs need to be present.

Capacity building

Training is an essential part of delivery and dissemination. This will be provided in part by the tutorial module, manual and help files. With this help the tool will be largely self explanatory. However some person-to-person training will be beneficial. The format of this training is still to be determined, but could take the form of training workshops.

Fostering uptake

Uptake of the tool will be fostered by maintaining ongoing links with users and potential users of the tool and in conjunction with capacity building and monitoring and evaluation.

Monitoring and evaluation

Monitoring and evaluation are also essential to the success of the tool. Feedback will be invited on a beta version of the tool and incorporated into subsequent releases of the tool. As with capacity building and fostering uptake, the important element here is to maintain open links with users and potential users. This process is also an important component of verification and validation of the tool, as much of the verification will based on results reported by users, along with expert assessment and testing with the limited data available from trial sites not included in the forages database.

Conclusions

Improved forages are often a suitable option for smallholder farmers in the tropics seeking to sustainably improve livelihoods. However for a number of reasons forage adoption, in particular legumes, is low. Providing information on forages and in particular their suitability to particular niches can equip farmers with the ability to make better informed decisions. The tool does not make the decisions for the farmers, but rather organizes and presents information in a way that can greatly aid in the decision-making process.

One way to deliver this information is via a spatial decision support system, linking biophysical, socio-economic and management factors to forage species site-specific suitability. The aim of this decision support tool is to reduce uncertainty and therefore risk by providing relevant and accurate information to introduce options which might otherwise have been ignored.

With such a system even the most traditional farmers like Banega can take advantage of current research into forage species, reducing the risk of making ill-advised choices and increasing the potential of their land, and ultimately increasing the value of their produce and their own well-being.

References

Barco F., Franco, M.A., Franco, L.H., Hincapie, B., Lascano, C., Ramírez, G. and Peters, M., 2002. Forrajes Tropicales: Base de Datos de Recursos Genéticos Multipropósito, Versión 1.0 (Tropical Forages Database). CIAT. http://www.ciat.cgiar.org/catalogo/producto.jsp?codigo=P0219

Berger T., 2001. Agent-Based Spatial Models Applied to Agriculture: a Simulation Tool for Technology Diffusion, Resource Use Changes and Policy Analysis. Agricultural Economics 25, 245-260.

Booth T.H., 1995. Predicting Plant Growth: Where Will it Grow? How Well Will it Grow? Third International Conference / Workshop on Integrating GIS and Environmental Modelling, National Center for Geographic Information and Analysis, Santa Fe, New Mexico, 21-25 Jan 1995.

Borland Software Corporation, 2002. Borland Delphi 6.0. Software. http://www.borland.com.

Chipeta S., Hoydahl E. and Krog J., 2003. Livestock Services and the Poor. A Global Initiative – Collecting, Coordinating and Disseminating Experiences. Draft Report, Danida, IFAD and The World Bank.

Cox P.G., 1996. Some Issues in the Design of Agricultural Decision Support Systems. Agricultural Systems 52(2-3), 355-381.

Crossland M.D., Wynne B.E. and Perkins W.C., 1995. Spatial Decision Support Systems: an Overview of Technology and a Test of Efficacy. Decision Support Systems 14, 219-235.

Delgado C., Rosegrant M., Steinfeld H., Ehui S. and Courbois C., 1999. Livestock to 2020: The Next Food Revolution. 2020 Brief 61, IFPRI http://www.ifpri.org/2020/briefs/number61.htm

ESRI, 2000. MapObjects LT 1.0. Software program. http://www.esri.com.

FAO, 2002, FAOSTAT, Food and Agriculture Organization of the United Nations http://apps.fao.org/default.htm

Hall G.B., Feick R.D. and Bowerman R.L., 1997. Problems and Prospects for GIS-Based Decision Support Applications in Developing Countries. South African Journal of Geoinformation 17(3), 81-87.

Hill M.J., 2000. Applications for Spatial Data in Grassland Monitoring and Management. In: Hill M.J. and Aspinall R. (Eds.), Spatial Information for Land Use Management, Gordon & Breach Science Publishers, New York, pp. 113-127.

Humphreys L.R., 1994. Tropical Forages: Their Role in Sustainable Agriculture. Longman Scientific and Technical, Essex, London.

McCown R.L., Hochman Z. and Carberry P.S., 2002. Probing the Enigma of Decision Support Systems for Farmers: Learning from Experience and from Theory. Agricultural Systems 74, 1-10.

Peters M., Horne P., Schmidt A., Holmann F., Kerridge P.C., Tarawali S.A., Schultze-Kraft R., Lascano C.E., Argel P., Stür W., Fujisaka S., Müller-Sämann K. and Wortmann C., 2001. The Role of Forages in Reducing Poverty and Degradation of Natural Resources in Tropical Production Systems. ODI Agricultural Research and Extension Network, Network Paper No. 117.

Schultze-Kraft R. and Peters M., 1997. Tropical Legumes in Agricultural Production and Resource Management: An Overview. Presented at the Tropentag JLU Giessen 22-23 May 1997. Giessener Beiträge zur Entwicklungsforschung 24:1-17.

Staal, S.J., 2003. Market Opportunities for Milk Producer Organisations. ILRI. http://www.cgiar.org/ilri/news/milkmarket.cfm

Staal S.J., Baltenweck I., Waithaka M.M., deWolff T. and Njoroge L., 2002. Location and Uptake: Integrated Household and GIS Analysis of Technology, Adoption and Land Use, With Application to Smallholder Dairy Farms in Kenya. Agricultural Economics 1682,1-21.

Stür W., Horne P., Gabunada F.A. Jr, Phengsavanh P, and Kerridge P.C., 2002. Forage Options for Smallholder Crop-Animal Systems in Southeast Asia: Working with Farmers to Find Solutions. Agricultural Systems 71(1-2), 75-98.

Thornton P.K., Kruska R.L., Henniger N., Kristjanson P.M., Reid R.S., Atieno F., Odero A.N. and Ndegwa T., 2002. Mapping Poverty and Livestock in the Developing World. ILRI, Nairobi, Kenya.

UN, 2003. United Nations Statistical Division - Millennium Indicators. http://unstats.un.org/unsd/mi/mi_series_results.asp?rowID=607&fID=r5&cgID=419

Walker D.H., 2002. Decision Support, Learning and Rural Resource Management. Agricultural Systems 72, 113-127.