# GIS based decision support system and its application in agroforestry

**J.P. Singh and M.M. Roy**
*Indian Grassland and Fodder Research Institute, Jhansi- 284003 (U.P.)*

**ABSTRACT :** Appropriate decision support systems based on available information and modern tools and technologies may serve as a valuable aid in dissemination of information in the field of agroforestry for the benefit of the end user. The computer based models may be extremely useful in efficient handling of many of the social, economic and ecological variables in a simplified manner. GIS is likely to play an important role in the integration of various types of spatial and non-spatial data set on a single platform and provide desired information in the form of maps and feature linked dataset. Also, such information may be essential for answering many of the quarries related to agroforestry interventions in an area.

**Keywords**: Agroforestry, decision support system, GIS, land resource characterization.

## 1. INTRODUCTION

Agroforestry, deliberate incorporation of trees or shrubs on private lands, is emerging as an important alternative land use systems across the globe on account of economic benefits as well a reduced soil erosion, improved water quality etc. (Rietveld 1995). India has a long tradition of agroforestry and it is influenced by a number of biophysical as well as socio-economic factors. Three decades of agroforestry research in the country has led to development of several agroforestry systems that are based on people's need and site specific characteristics. Presently, the expectations from agroforestry are quite high in this country both in rural and urban areas. In recent years sizable increase in tree cover outside the forest areas has taken place in many states (Kumar, 2008). However, it is realized that there exists tremendous scope of dissemination of knowledge to land owners, farmers and extension agents about not only the availability and suitability of various agroforestry options but also their management in such a complex environment. In order to achieve this, appropriate Decision Support Systems (DSS) may be used. Such a DSS has to cover a wide array of systems, tools and technologies in an interactive manner with the objective of helping managers and other clients to make decisions. It should provide a platform to its clients for retrieving, summarizing and analyzing data relevant for decision making. In this paper an attempt has been made to present a review of various decision support systems that may be useful in the context of agroforestry in a variety of ways.

## 2. AGROFORESTRY DATABASES

Agroforestry Systems Inventory Databases (AFSI) have been developed by the International Centre for Research in Agroforestry (ICRAF), now the World Agroforestry Centre (WAC) Nairobi. AFSI involved a global collection of data or information on agroforestry systems using a questionnaire as the survey instrument. Data and information collected and entered into the database included general description, geographical location, biophysical characteristics, socioeconomic aspects, system evaluation, components of the system and their uses and identification of research gaps. With AFSI, the user is able to query the database, extracting information such as geographical locations of different agroforestry systems and the species found within these systems in different locations (Nair 1987; Oduol *et al.* 1988). AFSI was apparently developed as a research and information tool for researchers. Unfortunately, AFSI often fail to be maintained and upgraded and therefore fade with time.

Earlier a database entitled Multipurpose Tree and Shrub Database (MPTS) was developed by ICRAF in 1991 (Von Carlowitz *et al.* 1991). It was meant for the researchers and extension agents as an aid to select the right tree or shrub species for agroforestry practices. This database was primarily meant for the tropics and subtropics containing information on 1093 species on the aspects related to site-specificity, morphological and phenological descriptions, management characteristics and environmental responses. A simple climate model was included to predict climatic conditions based on the input of geographical coordinates. Tree and shrub species were selected via a database search that matched the descriptors that the user selected. The descriptors included 19 different criteria covering aspects of location, climate and soil conditions, products, environmental services, management and cultivation. References were also included to provide further information on selected agroforestry species (Schroder and Jaenicke 1994).

The current and revised version of MPTS is now the Agroforestry Tree Database (AFTD). It is a database management system intended for use by researchers and fieldworkers to select agroforestry trees that are being deliberately grown and managed for more than one output and expected to make significant economic and/or ecological impacts (Salim *et al.* 1998; World Agroforestry Centre 2003a).

In India, first workshop on agroforestry was organized by the Indian Council of Agricultural Research (ICAR) at Imphal in 1979 to compile and organize the information related to research and development of agroforestry. Since then a lot of spatial and attribute information have been generated. In this direction an important work on agroforestry information system was initiated by NRCAF, Jhansi. Web based application "agroforestryBASE" was designed and developed (Ajit, *et al*, 2005). It includes six databases *viz.*, Research Project Database, Database on Economic Analysis, Database on MPTS, Agroforestry Interventions and Poplar and Eucalyptus based Bibliographic Systems.

## 3. COMPUTER APPLICATION

In the recent past the use of computer based technologies in agroforestry and natural resource management has been impressive. Like in most natural resource management options, agroforestry is characterized by high complexity of which we have limited understanding and data (Sanchez 1995; Nair 1998). However, the advanced cartographic science and its application in agroforestry can be greatly enhanced through the use of GIS (Geographic Information System), GPS (Global Positioning System) and SRS (Satellite Remote Sensing). Important categories of computer-based spatial information technologies are presented in Table 1.

Table 1. Major categories of useful computer based spatial information technologies for agroforestry.

| Category | Description |
|---|---|
| Databases | Organizes and facilitates the management and querying of large quantities of data and information |
| Geographical Information Systems (GIS) | Brings in a geographic or spatial component to a database; manages, manipulates and analyzes spatial data |
| Computer Based Models | Mathematical computer models that represent real world processes and predict outcomes based on input scenarios |
| Knowledge Based or Expert Systems | Adopts 'Artificial Intelligence' in the form of organizing, manipulating and obtaining solutions using knowledge in the form qualitative statements, expert rules and a computer language representation system for storing and manipulating knowledge. |
| Hybrid Systems | Integrates two or more of the above computer-based technologies (*e.g.* GIS, KBS and Models) for more versatile, efficient and comprehensive DSTs. |

## 4. GIS APPLICATIONS

Geographic Information System (GIS) can be defined as a data management system designed to input, store, retrieve, manipulate, analyze, and display spatial data for the purpose of research and decision-making (De Mers 1997). Use of GIS can facilitate the planning process of agroforestry development. Spatial data layers like soil type, slope, and land cover can be used to develop suitability assessments that can identify optimal locations for agroforestry practices to solve landowner and community concerns.

The Land Cover Classification System (LCCS) has already been developed by the Food and Agriculture Organization (FAO) of the United Nations Environment Programme (UNEP) to meet the need for improved access to reliable and standardized information. By selecting data with the appropriate spatial resolution, this assessment process can be used at any scale for design and management of different agroforestry options. The most significant benefit of using GIS-guided DSS is the ability to combine different assessments to determine locations where multiple objectives can be achieved. In a GIS, a database is associated with map features and data values are geographically referenced, so resource managers can spatially represent information such as soil types or plant communities. Since land use and a diversity of related disciplines (agriculture, forestry, rural planning, and conservation) all deal with spatial characteristics of landscapes (Lacher 1998); GIS has gained considerable use in land use planning and natural resource management, providing a spatial framework to aid in the decision-making process (Zeiler 1999).

As the GIS technology is widely available and affordable today and agroforestry is directly dependent upon spatial characteristics; it is logical to expect to have several agroforestry-specific GIS based DSSs. Ellis *et al* (2004) have reviewed many DSS tools used in agroforestry research and development. Several such systems are depicted in Table 2. The USDA National Agroforestry Center (NAC) is currently using GIS to facilitate conservation buffer planning in the Western Corn Belt eco-region the central United States (Bentrup *et al.* 2000). GIS guided assessments are being used to evaluate four key issues of the Western Corn belt: biodiversity, soil protection, water quality, and agroforestry products. By combining these assessments, information is generated for use in identifying opportunities and constraints on the landscape where multiple benefits from conservation buffers, especially agroforestry plantings, can be achieved (Bentrup *et al.* 2000). Most of the past agroforestry GIS applications mentioned above have been research-oriented. The Southeastern Agroforestry Decision Support System (SEADSS), developed by the Center for Subtropical Agroforestry (CSTAF) at the University of Florida brings on-line GIS capabilities directly to extension agents and landowners. It offers county soils, land use and other spatial data for selecting suitable tree and shrub species in a specified location (Ellis *et al.* 2003).

Table 2. GIS based decision support tools used in agroforestry

| GIS based decision support tool | Type | Important features |
|---|---|---|
| AFSI (Agroforestry Systems Inventory Database) (Nair 1987; Oduol *et al.*1988) | Database | Agroforestry system inventory database describing geographic location and biophysical, socioeconomic and species characteristics |
| MPTS (Multipurpose Tree and Shrub Database) (Schroder and Jaenicke, 1994) | Database | Multi-purpose tree and shrub database used for tree selection and species information |
| AgroforesTree Database (Salim *et al.* 1998; World Agroforestry Centre 2003a) | Database | Internet and CD-Rom application for reference and selection guide of agroforestry trees. |
| Subtropical Tree and Shrub Database (Ellis *et al.* 2003) | Database | On-line database on potential agroforestry tree and shrub species for the American subtropics. |
| Forestry Compendium (CABI 1998; Kleine *et al.* 2003) | Database | Compilation of knowledge on forestry, Agroforestry and plantations and information on trees for management decision-making and species selection |
| Agroforestry System Suitability in Africa (Booth et al. 1989; Booth et al. 1990; Unruh and Lefebvre 1995) | GIS | Spatial analysis using climate, soil land use and other spatial data alongside plant species data to determine species and agroforestry suitability |
| Agroforestry System Suitability in Ecuador (Bydekerke *et al.* 1998) | GIS | Spatial analysis to determine suitable areas of Annona cherimola agroforestry systems in Southern Ecuador. |
| Agroforestry System Assessment in Nebraska (Bentrup and Leininger,2002) | GIS | Spatial suitability assessment for willow and forest farming agroforestry systems in a Nebraska watershed |
| Agroforestry Parklands in Burkina Faso (Bernard and Depommier 1997) | GIS | Spatial analysis of dynamics of agroforestry parklands and species distribution due to human impacts |
| Historical Transformation of Agroforestry Landscape in Canada (Paquette and Domon 1997) | GIS | Spatial analysis of census and geomorphologic data to explore dynamics of agroforestry in 19th century Canadian landscape |

| | | |
|---|---|---|
| Field-level spatial analysis of temperate agroforestry system (Jose *et al.* 2001) | GIS | Spatial analysis using ground penetrating radar (GPR) to evaluate root biomass and distribution and soil nutrient crop-tree interactions in temperate alley cropping |
| AME(Agroforestry Modeling Environment) (Muetzelfeldt and Taylor 1997) | Modeling Tool | Object-oriented tool to graphically visualize, construct, integrate and exchange agroforestry models |
| FALLOW (World Agroforestry Centre 2003c; Van Noordwijk 2002) | GIS and Model | Model to evaluate impacts of shifting cultivation and fallow rotations at a landscape-scale evaluating transitions in soil fertility, crop productivity, biodiversity and carbon stocks World Agroforestry |
| Agroforestry Planning Tool in China (Liu *et al.* 1999) | Hybrid GIS, Models and KBS | Hybrid DST integrating GIS data, regression models plus expert knowledge to assess biophysical, social and economic suitability of Paulownia intercropping agroforestry systems |
| PLANTGRO (Plantation and Agroforestry Species Selection Tool) (Booth 1996; Hackett and Vanclay 2003) | Hybrid GIS/ KBS | Plantation and agroforestry species selection tool integrates GIS and expert system on plant growth |
| SEADSS (Southeastern Agroforestry Decision Support System) (Ellis *et al.* 2003) | Hybrid Database, GIS, KBS | Landscape and site-scale agroforestry planning and species selection DST for landowners and extension agents of Southeast US that integrates GIS, tree and shrub database and expert knowledge |
| agroforestryBASE (Agroforestry Information System) (Ajit *et al.* 2005) | Database | An internet based agroforestry information quarry and data retrieval system |

## 5. DESIGNING OF DECISION SUPPORT SYSTEM

With the growing interest in agroforestry options in irrigated as well as rainfed situations of the country it is important to design decision support systems using modern tools based on integration of various types of spatial and non- spatial data set on a single platform. The end product may be in the form of maps and feature linked dataset.

A model example of such an effort at regional level (Bundelkhand region of India) is described. Pathak and Roy (1995) worked out the agroforestry strategy for this region based on the present land use and cropping pattern in rainfed as well in irrigated situations. The opportunities for practicing agroforestry in this region included forest fringes, fallows and wastelands (Pathak and Singh, 2003). Using spatial (IRSP6) and attribute information, land suitability classes (type 1 to type 5) for a variety of agroforestry options in the Bundelkhand region has been generated (using ArcGIS ArcInfo Workstation ver.9.2) and presented in Figure 1. Such DSSs may find useful application in agroforestry on a regional basis. However, groups of information are required to be generated and spatially integrated to build geo-database for the designing of a suitable DSS. A scheme for creation of such data bases is depicted in Figure 2.

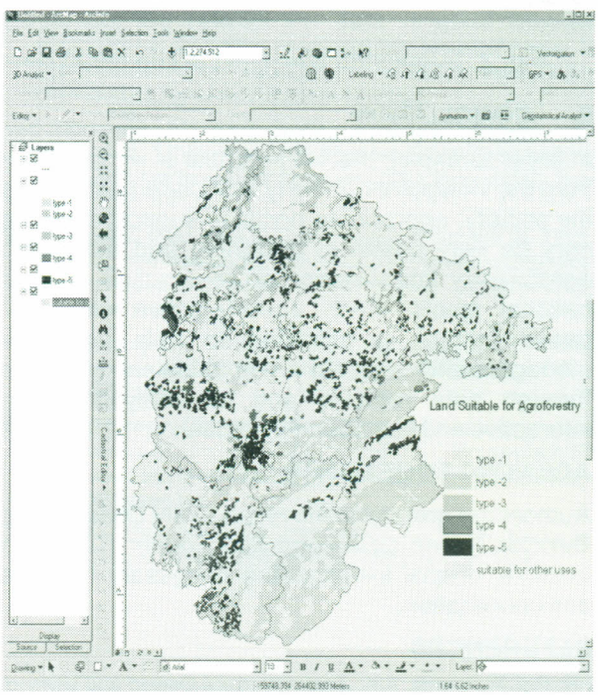


Fig. 1. Geo-database based on land suitability classes for practicing agroforestry in Bundelkhand region of India

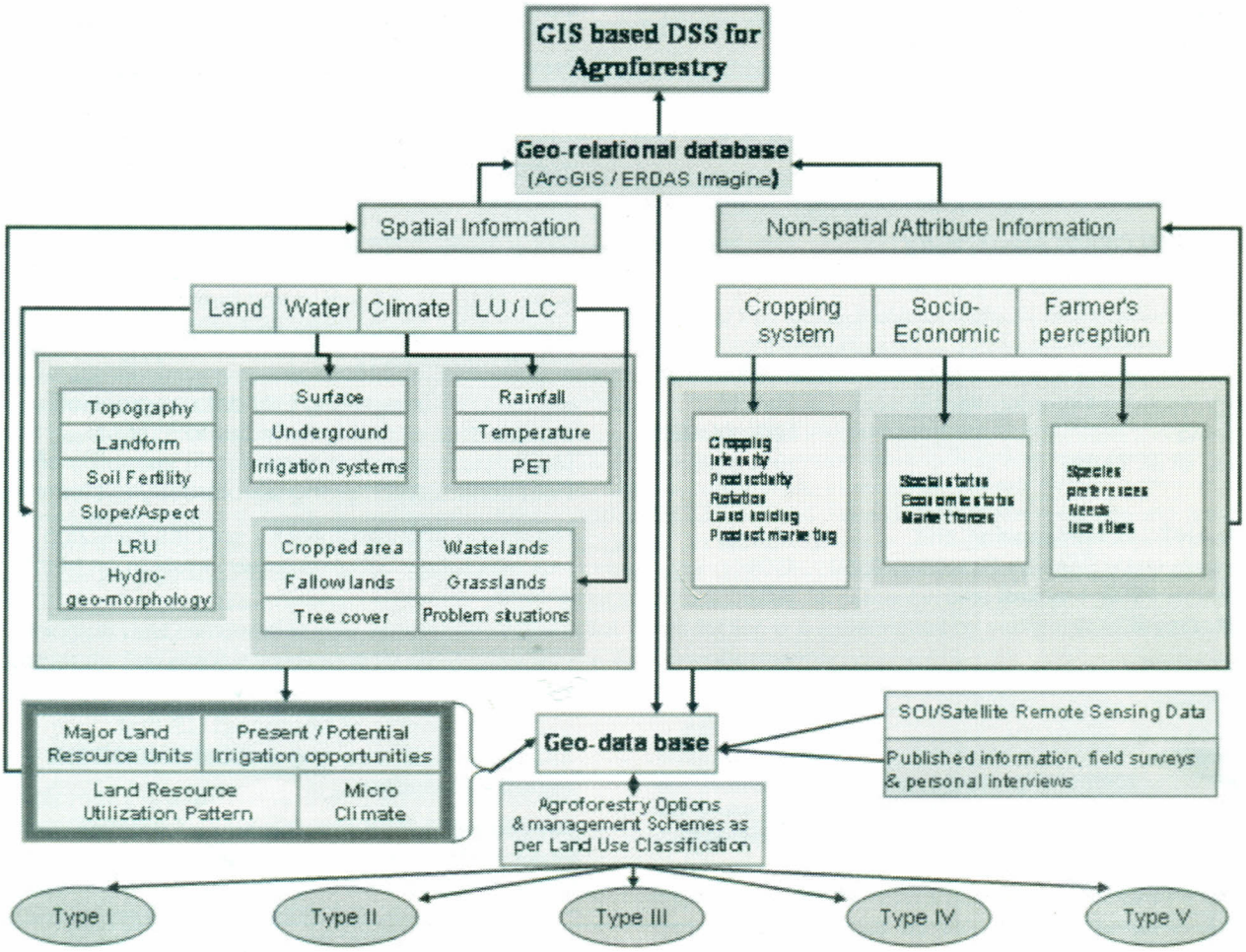


Fig. 2. Suggested flow chart of GIS based Decision Support System for agroforestry interventions in India

## 6. CONCLUSION

In order to exploit the full potential of agroforestry from the viewpoints of many associated benefits to the society; appropriate decision support systems may be very useful in designing and managing agroforestry interventions on regional as well as national levels. Such an interactive computer based system is expected to help planners, managers and clients to arrive at logical decisions through data retrieval and its analysis in an interactive and user friendly manner.

## ACKNOWLEDGEMENTS

Authors are grateful to the Head, GSM Division and Director, Indian Grassland and Fodder Resaerch Institute, Jhansi for providing necessary facilities and cooperation.

## REFERENCES

Ajit, Rai, P., Handa, A.K. 2005. Structure Design and Utility of Agroforestry Information System "agroforestryBASE." National Research Centre for Agroforestry. Jhansi.

Bentrup G. and Leininger T. 2002. Agroforestry mapping: the way GIS. J Soil Water Conserv. 57: pp.148153.

Bentrup G., Dosskey M., Schoeneberger M., Wells M., Leininger T. and Klenke K. 2000. Planning for multi-purpose riparian management. In:Wigington P.J. and Beschta R.L. (eds), Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association, Middleburg, VA. pp. 423426.

Bernard C. and Depommier D. 1997. The systematic approach and the role of GIS in the characterization and monitoring of agroforestry parks. XI World Forestry Congress, Antalya, Turkey, 13 to 22 October 1997, Vol. 1., 87p.

Booth T.H. 1996. Tree selection and growth improvement. In: Dieters M.J., Matheson A.C., Nikles D.G., Hardwood C.E. and Walker S.M. (eds), Tree Improvement for Sustainable Tropical Forestry: Proceedings of OFRI-IUFRO Conference. Queensland Forestry Research Institute. Gypie, Qld, Australia. pp. 311 316.

Booth T.H., Stein J.A., Hutchinson M.F. and Nix H.A. 1990. Identifying areas within a country climatically suitable for particular tree species: an example using Zimbabwe. Int Tree Crops J. 6: 116.

Booth T.H., Stein J.A., Nix H.A. and Hutchinson M.F. 1989. Mapping regions climatically suitable for particular species: an example using Africa. Forest Ecol Manag 28: 1931.

Bydekerke L., Van Ranst E., Vanmechelen L. and Groenemans R. 1998. Land suitability assessment for cherimoya in southern Ecuador using expert knowledge and GIS. Agric Ecosys Environ 69: 8998.

CABI (Commonwealth Agricultural Bureau International) 1998. The Forestry Compendium: A Silvicultural Reference. CABI, Oxford, United Kingdom. CD-ROM.

De Mers, M.N. 1997. Fundamental of Geographic Information Systems. Wiley, New York, 486p.

Ellis E.A., Nair P.K.R., Linehan P.E., Beck H.W., Blanche C.A.2000. A GIS-based database management application for agroforestryand tree selection. Computers and Electronics in Agriculture.27: 4155.

Ellis, E.A., Nair P.K.R. and Jeswani S.D. 2003. The southeastern agroforestry decision support system (SEADSS): a Web-based application for agroforestry planning and tree selection. In: Vacik H., Lexer M.J., Rauscher M.H., Reynolds, K.M. and Brooks R.T. (eds), Decision Support for Multiple Purpose Forestry. A Transdisciplinary Conference on the Development and Application of Decision Support Tools for Forest Management. 2325 April 2003, University of Natural Resources and Applied Life Sciences, Vienna Austria, CD-ROM. pp. 112.

Ellis, E.A., Bentrup, G. and Schoeneberger, M.M. 2004. Computer-based tools for decision support in agroforestry: Current state and future needs. Agroforestry Systems 61: 401421.

Hackett, C. and Vanclay J.K. 2003. Mobilizing expert knowledge of tree growth with the PLANTGRO and INFER systems. Plantsoft Services, Stirling Australia and CIFOR, Jakarta, Indonesia, 18 pp.

Jose S., Gillespie A.R., Seifert J.R. and Pop P.E. 2001. Comparison of minirhizotron and soil core methods for quantifying root biomass in a temperate alley cropping system. Agroforest System 52:161168.

Kleine, M., Scott P., de Neergard N.B., Pasiecznik N. and Becker K. 2003. New technologies to support decision making and global collaboration in multiple-purpose forest managementthe Forestry Compendium and the Global Forest Information System. In: Vacik H., Lexer M.J., Rauscher M.H., Reynolds K.M. and Brooks R.T. (eds), Decision Support for Multiple Purpose forestry. A Transdisciplinary Conference on the Development and Application of Decision Support Tools for Forest Management. April 2325, 2003, University of Natural Resources and Applied Life Sciences, Vienna Austria, CD-ROM. pp. 1-10.

Kumar Anoop. 2008. Valuation and Evaluation of Trees outside Forest (TOF) in India. Forest Survey of India, Ministry of Environment and Forests, Kaulagarh Road, PO: IPE Dehradun, India. (Website: http://www.unescap.org/stat/envstat/stwes-env3b.pdf)

Lacher, T.E. 1998. The spatial nature of conservation and development. In: Savitsky B.G. and Lacher T.E. (eds), GIS Methodologies for Developing Conservation Strategies: Tropical Forest Recovery and Wildlife Management in Costa Rica. Columbia University Press, New York, NY. pp. 312.

Liu J., Shao G. and Li W. 1999. Expert knowledge-based model for regional agroforestry planning. In: Li B Geoinformatics and Socioinformatics: The Proceeding of Geoinformatics'99 Conference. Ann Arbor, Michigan, 1921 June. University of California, Berkely, CA. pp. 18.

Muetzelfeldt, R.B. and Taylor, J. 1997. The Agroforestry Modelling Environment. In: Agroforestry Modelling and Research Coordination. Annual Report to ODA July 1996-June 1997. Institute of Terrestrial Ecology. Natural Environment Research Council. Edinburgh, UK. pp. 1020.

Nair, P.K.R. 1987. Agroforestry System Inventory. Agroforest System 5: 319338.

Nair, P.K.R. 1998. Directions in tropical agroforestry research: past, present and future. Agroforest System 38: 223245.

Oduol, P.A., Muraya P., Fernandes E.C.M. and Nair, P.K.R. 1988. The agroforestry systems database at ICRAF. Agroforest System 6: 253270. 420

Paquette, S. and Domon G. 1997. The transformation of the agroforestry landscape in the nineteenth century: a case study in southern Quebec, Canada. Landscape Urban Plan 37: 197209.

Pathak, P.S. and Roy M.M., 1995. Agrosilvipastoral farming systems for optimizing forage and energy resources in rainfed areas, In: (Singh, R.P. ed.) Forage Production and Utilization, Indian Grassland and Fodder Research Institute, Jhansi. pp. 154-178.

Pathak, P.S. and Singh J.P. 2003. Bundelkhand: Perspective and Agroforestry Prospects. Souvenir, National Symposium on Agroforestry and Sustainable Production & Silver Jubilee of Agroforestry in India. Nov.7-9. NRCAF, Jhansi. pp. 28-40.

Rietveld, W.J. 1995. Agroforestry: a maverick science and practice. In: Rietveld, W.J. (ed.) Proceedings of Agroforestry and Sustainable Systems Symposium, August 7-10, 1994, Fort Collins, CO. General Technical Report RM-GTR-261. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Salim, A.S., Simons A.J., Waruhiu A., Orwa C. and Anyango C. 1998. Agroforestry Database: A Tree Reference and Selection Guide. Version 1.0. ICRAF. Nairobi, Kenya. CD-ROM.

Sanchez, P.A. 1995. Science in agroforestry. Agroforest System 30: 555.

Schroder, J.M. and Jaenicke H. 1994. A computerized database as decision support tool for the selection of agroforestry tree species. Agroforest System 26: 6570.

Unruh, J.D. and Lefebvre P.A. 1995. A spatial database approach for estimating areas suitable for agroforestry in sub-Saharan Africa: aggregation and use of agroforestry case studies. Agroforest System 32: 8196.

Van Noordwijk, M. 2002 Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. Ecol Model 149: 113126.

Von Carlowitz, P.G., Wolf G.V. and Kemperman R.E.M. 1991. Multipurpose Tree and Shrub Database: An Information and Decision Support System. ICRAF, Nairobi, Kenya & GTZ, Eschborn, Germany. 104p.

World Agroforestry Centre 2003a. Agroforestry Database. http://www.worldagroforestrycentre .org/Sites/TreeDBS/AFT/AFT.htm

World Agroforestry Centre 2003c. Forest, Agroforest, Lowvalue Landscape or Wasteland? http://www.worldagroforestrycentre.org/sea/agromodels/FALLOW/fallow.htm

Zeiler, M. 1999. Modeling our world: the ESRI guide to geodatabase design. ESRI Press. Redlands, CA. 199p.