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Review article

Application of information technology and GIS in agroforestry

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Abstract: Computer-based Decision Support Tools (DST) helps to integrate information to facilitate the decision-making process that directs development, acceptance, adoption, and management aspects in agroforestry. Computer-based DSTs include databases, geographical information systems, models, knowledge-base or expert systems, and 'hybrid' decision support systems. Although agroforestry lacks the large research foundation of its agriculture and forestry counterparts, the development and use of computer-based tools in agroforestry have been substantial and are projected to increase as the recognition of the productive and protective (service) roles of these tree-based practices expands. The utility of these and future tools for decision-support in agroforestry must take into account the limits of our current scientific information, the diversity of aspects (*i.e.* economic, social, and biophysical) that must be incorporated into the planning and design process, and, most importantly, who the end-user of the tools will be. Incorporating these tools into the design and planning process will enhance the capability of agroforestry to simultaneously achieve environmental protection and agricultural production goals. This paper highlights the relevance of information technology (IT) in Agroforestry. Existing areas of applications such as forest and environmental management, specie identification and research publications are identified. The paper also looked into future possible usage of information technology and concludes that while the application of information technology to Agroforestry practices nowadays is of tremendous importance it is important to know that there are still more areas where information technology would be applicable in Agroforestry which are yet to be discovered.

Keywords: Forest management - Information technology - Agroforestry education.

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INTRODUCTION

Within half a century, computers and information technology have changed the world and affected millions of lives in ways that no one could have foreseen (Heathcote 2000). The great impacts, contributions to knowledge, importance and economic achievements that have emerged from the fields of computer science (information science) and electronic engineering, in the 21st century, are revolutionary and mind boggling (Bamgbade 2011). The extent to which IT applications have improved agro-forestry practices in recent times cannot be over emphasized. Area of application includes:

Forestry and environmental management, species identification, research publication, Information Communication Technology ICT in agro forestry education, plant pathology studies, wood anatomy, biometrics, Data management, modelling, analysis and mining. The list is infinite; however some of these applications would be discussed in the present paper.

Advances in information and communications technology (ICT) and knowledge management (KM) have changed the way people learn and e-learning is increasingly recognized as a viable and learner-friendly approach that can complement, or even replace, more traditional training and education approaches. Agriculture however is a very practical subject and not all of it can be generalized at a global level since local context will largely determine success or failure of agricultural and natural resources management innovation. The management of plant genetic resources for example involves practices that are almost impossible to teach in an

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online environment and transmission of knowledge is often better achieved through peer-to-peer learning (Baena *et al*. 2007). Likewise, many agricultural practices need to be adapted to local biophysical and socioeconomic conditions if they are to be successfully adopted by those they intend to serve. Blended learning, combining an online, more general learning experience with more practical face-to-face problem solving activities, has the potential to include more learners while dealing with the issues of practicality and contextualization.

Agroforestry, the deliberate integration of trees into crop and livestock operations, has the potential to achieve many of the environmental, economic, and social objectives being demanded from working landscapes by landowners and society (Fig. 1). By adding structural and functional diversity to the landscape, these tree-based plantings can perform ecological functions that have significance far greater than the relatively small amount of land they occupy (Guo 2000, Nair 2001, Ruark *et al*. 2003). Realizing this potential is, however, a complex task of determining what opportunities, limitations, and trade-offs exist in each situation, and of designing an agroforestry practice that achieves the best balance among them. There are numerous impacts created by agroforestry plantings, ranging from intended to non-intended and, therefore, ranging from detrimental to advantageous, occurring both on- and off-site, and varying over time. Consequently, if agroforestry is to be a viable strategy in promoting agro-ecosystem sustainability, the decision making process must incorporate many considerations, not only at the practice scale but also at the larger scales of farm, landscape, and watershed (Schoeneberger *et al*. 1994). Simply putting, agroforestry creates a complex system of interactions that must be managed for multiple objectives, multiple alternatives and multiple social interests and preferences, while being applied over a wide range of landscapes and landscape features.

Figure 1. Wheat based agro-forestry system with: **A,** Walnut; **B,** Salix.

The decision-making process involved in agroforestry research, development and application is composed of several components: the person or group making the decision, the problem, the approach or method to solve the problem, and the decision. Decision support tools (DST) are a wide variety of technologies that can be used to help integrate diverse and large sets of information. DSTs do not replace the decision-making by the landowner or natural resource manager, but they do facilitate the decision-making process by making the planning process more informed and more objective (Grabaum & Meyer 1998). Although agroforestry, like most natural-resource management sciences, is characterized by high complexity of which we have limited understanding and data (Sanchez 1995, Nair 1998), the science and application of agroforestry can be greatly enhanced through the use of these tools.

FOREST AND ENVIRONMENTAL MANAGEMENT

Mathematical and computational programming in Forest Management

Mathematical and computational programming remains a viable approach for strategic planning in forestry and agriculture worldwide. One of such computational based system is the SPECTRUM used by the United State government to carry out strategic planning in agroforestry. The system which evolved from an earlier system (FORPLAN) has the following key attributes:

1. Multi-resource modeling

The system provides a generic framework for modelling any resource. A basic configuration depends on user-defined analysis units, management actions, activities and outputs, resource coefficients, and economic information.

2. Spatial and temporal scales

Spectrum applications are not scale-specific. Up to 90 time periods of any length may be used to support analysis at relevant spatial and temporal scales.

3. Multiple options for mathematical programming

Spectrum supports numerous combinations of optimization techniques and objective functions. Optimization techniques includes,

• Linear programming (optimization of a single criterion).
• Mixed-integer programming (optimization with categorical outcomes).
• Multi-objective goal programming (simultaneous optimization of multiple goals).
• Stochastic programming to account for random events such as fires, pest epidemics, and uncertainty about data.

Specifications for objective functions

Options for objective functions in traditional linear programming include maximizing or minimizing a single outcome or measure of performance. Objective Functions for goal programming include minimizing under-achievement of goals, minimizing over- achievement of goals beyond thresholds, or minimizing both.

Two additional options for objective functions are MAXIMIN (maximizing the minimum level of occurrence for a critical resource) and MIN/MAX (minimizing the highest level of occurrence of an undesirable outcome).

Simulation of ecological processes and modelling natural disturbance

Spectrum allows embedding simulation of ecological processes and modelling of natural disturbances by means of state, flow, and accessory variables in dynamic equations.

The Regional Ecosystems and Land Management (RELM) system extends the utility of Spectrum solutions by apportioning forest-wide, strategic planning solutions to tactical sub-units of the forest such as watersheds.

Cumulative effects and connected actions can be analysed both within and between sub-units, allowing planners to evaluate how alternative management scenarios affect neighbouring units.

Research publication

Information dissemination is a prominent activity in any research institute as it is the means through which it could be adjudged whether it is living up to the mandate and purpose for which, it was established. Also, research publications play a pivotal role in any academics environment. Paper publication is a useful instrument through which research discoveries and breakthroughs are disseminated to the stakeholders. However, publishing research papers in a manual format is attached with great difficulties and problems, which includes ineffective and inefficient delivery system of the journal as at when due, prone to natural disasters, lost, theft, mutilation. Sequel to the aforementioned problems, a software (FRIN –eJOURNAL: An Electronic Submission Platform for Research papers) has been developed in FRIN which would allow for easy electronic retrieval, storage and efficient research information delivery system. It will go a long way to automate the existing manual journal with easy search tool and navigation properties, providing researchers, administrator and FRIN editors with separate interface with hands on functionality and notification capability also creating a proper record of subscribers and records of subscription. It is cost effective and is not regional bound.

Species identification

Although automated species identification for many reasons is not yet widely employed, efforts towards the development of automated species identification systems within the last decade is extremely encouraging; that such an approach has the potential to make valuable contribution towards reducing the burden of routine identification.

There are many factors influencing the taxonomic impediment to the study of biodiversity. A major one being that the demand for routine identification in biodiversity studies extends beyond the available resources. In many spheres the volumes of plant or animal specimens that can usefully be obtained, particularly using modern sampling methods, vastly outstrip any capacity to identify this material. This has limited the progress in some aspect of biodiversity research. These demands are likely to steadily increase as the proportion of previously un-described species in local, national or regional floras and fauna declines and as requirement or desirability of biodiversity inventories and other such survey grows.

This has led to several solutions being preffered to reduce the burden of routine identification. One of the preffered solutions is automating the identification process in some way. This is generally referred to as Computer Assisted Taxonomy (CAT). However, the development and application of an automated approach to taxonomic identification has remained a minority interest till date.

Among reasons for this are the notions that it is too difficult, too threatening, too different or too costly. It is most encouraging to know that despite these limitations, efforts towards the development of automated species identification systems have been progressive.

From the evidences witnessed in this area, it buttresses the present minority notion that the automation of species identification process is possible and achievable. A system that uses binary codes generated based on the morphological characters of trees to uniquely identify tree species has been developed. Though this is not the first time an attempt is made to automate species identification using their morphological characters, our approach is far simpler and less expensive to implement. For instance while previous approaches are centred round the need for a computerized pattern recognition system, ours does not require such. We were able to easily prove the effectiveness of the system by restricting our study to the over one thousand Nigerian Trees species. All the user need is a functional computer system, a ruler and personal ability to supply answers to the questions asked by the system and the tree identification process is complete.

INFORMATION TECHNOLOGY IN AGRO FORESTRY EDUCATION

Information technologies (ITs) have the potential to enhance access, quality, and effectiveness in education in general and to enable the development of more and better teachers (Fig. 2). As computer hardware becomes available to an increasing number of schools, more attention needs to be given to the capacity building of the key transformers in this process, namely, teachers.

While societies undergo rapid changes as a result of increased access to information, the majority of the school going youth continues to undergo traditional rote learning. Very little is done to take advantage of the wealth of information available on the Internet. Whereas the processing of information to build knowledge is one of the essential literacy skills vital for the workforce in the 21st century, it is often overlooked in current educational practices. The Computers for Schools Program appears to be doing valuable work and in the process has become an unwitting champion of ITs in education. Its experiences are real, its challenges huge, and the lessons valuable for the future resource for poor countries. In order to function in the new world economy, students and their teachers have to learn to navigate large amounts of information, to analyse and make decisions, and to master new knowledge and to accomplish complex tasks collaboratively. Overloaded with information, one key outcome of any learning experience should be for learners to critically challenge the material collected in order to decide whether it can be considered useful input in any educational activity.

This is the basis for the construction of knowledge. The use of ITs as part of the learning process can be subdivided into three different forms: as object, aspect or medium.

- As object, one refers to learning about ICTs as specific courses such as 'computer education.' Learners familiarize themselves with hardware and software including packages such as Microsoft Word, Microsoft Excel, and others. The aim is computer literacy.
- As aspect, one refers to applications of ICTs in education similar to what obtained in industry. The use of ITs in education, such as in computer-aided design and computer aided agroforestry technology, are examples.
- ITs are considered as a medium whenever they are used to support teaching and learning.

The use of IT as a medium is rare where the availability of resources is a major obstacle to the widespread integration of ITs in education. In order to sustain what has already been done and expand into areas still unreached. Sequel to this is the need to explore the use of ITs in education, such as in computer-aided design and computer-aided agroforestry technology, are examples.

Need of applications of ITs in Agroforestry Education

With the advent of IT, it is found that IT forms the "backbone" of several industries and is today a dominant force in enabling companies to exploit new distribution channels, create new products, and deliver differentiated value added services to customers. IT is also an important catalyst for social transformation and national progress. Disparities in levels of IT readiness and usage could translate into disparities in levels of productivity and, hence, different rates of economic growth. It is also important to observe that ICTs can lead to economic growth but not development. The social exclusion of large groups of persons, especially women, children, and people living in rural areas, is a common phenomenon when adequate planning has not accompanied IT exploitation. Education faces a number of problems. These problems include the shortage of qualified teachers, very large student populations, high drop-out rates of students and teachers, and weak curricula.

All of these negative aspects result in poor delivery of education. The education crisis is worsened by the devastating effects of increasing poverty, a brain drain in the teaching community, budgetary constraints, poor communication, and inadequate infrastructure. Technology is not new to education. However, contemporary computer technologies, such as the Internet, allow new types of teaching and learning experiences to flourish. Many new technologies are interactive, making it easier to create environments in which students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge.

Access to the Internet gives unprecedented opportunities in terms of the availability of research material and information in general. This availability of research material and information happens to both inspire and threaten teachers. ITs are one of the major contemporary factors shaping the global economy and producing rapid changes in society. They have fundamentally changed the way people learn, communicate, and do business. They can transform the nature of education – where and how learning takes place and the roles of students and teachers in the learning process.

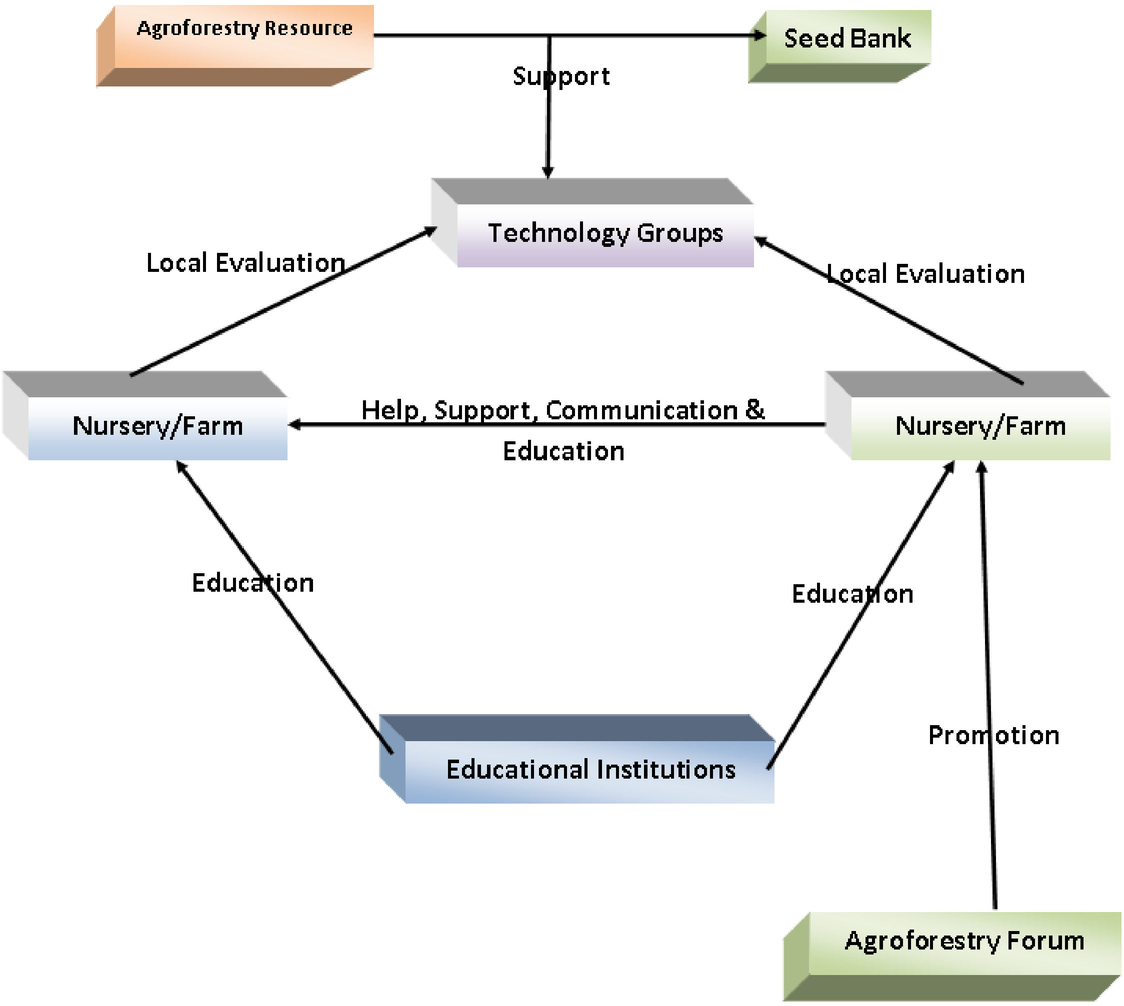

Figure 2. Application of information technology in agro forestry.

IT application in agroforestry

Diagnosis and Design methodology is a methodology for the diagnosis of land-management problems and the design of agro forestry solutions. There is a need to develop programmes to assist agroforestry researchers and fieldworkers to plan and implement effective research and development projects. From on-farm research trials, more rigidly controlled on-station investigations, and eventual extension trials in an expanded range of sites. It provides a basis for prompt feedback and complementarities between different project components. In an integrated agroforestry research and extension program, pivotal decisions can be made in periodic meetings of the various project personnel who evaluate new results and revise the action plan accordingly. The process should be continue until the design is optimal and further refinement is deemed unnecessary.

Research and development

To advance agro forestry, research is needed both on basic, process-level questions and on applied management techniques that are appropriate for commercial farm or forest operations. While basic research may, for example, investigate the long-term biological interactions between the components of an agro forestry practice, applied research should seek to maximize the tangible short and intermediate term benefits. Agro forestry practices should be tailored to readily integrate into existing farming or forestry enterprises, minimize the displacement of existing crops, use equipment and technical skills that are readily available, and allow some harvesting of products within conservation agro forestry practices (*e.g.* hardwood timber from riparian buffer strips). There is the potential to expand the participation of state, community and institutions, through their agriculture and forestry programs, in agro forestry research.

The greatest research need is to develop farm-level analyses of the potential economic costs, benefits, and risks associated with agro forestry practices. This information is a vital prerequisite to the objective comparison of both production-and conservation-driven agro forestry practices with alternative land use options. Furthermore, attention should be given to evaluations of future price trends in regional, national and international markets for commodities that can be produced using agro forestry (*e.g.* hardwood lumber or high-value, wind-sensitive crops). Research on tree-crop-animal-environment interactions should be pursued to provide a scientific basis for optimizing agro forestry designs.

GIS and Remote Sensing in Environmental Management

Use of geographic information systems (GIS), a collection of computer hardware and software used to analyse and display geographically referenced information, can facilitate planning process. A GIS can be defined as a data management system designed to input, store, retrieve, manipulate, analyse, and display spatial data for the purposes of research and decision-making (DeMers 1997). 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 (*i.e.* 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).

Additional technologies are often associated with GIS, such as Global Positioning Systems (GPS) and remote sensing. GPS is a means for inputting spatial data with real world coordinates into a GIS and has become an important tool for researchers locating and recording information in the field. Remote sensing involves using spatial data from photographic and satellite images, and software tools to analyse and interpret these data. Rhind (1988) defined GIS as “a computer system for collecting, checking, integrating and analysing information related to the surface of the earth”. As it were, there is an ever increasing recognition of the need to perform large scale mapping and map analysis operations for a wide variety of traditionally manual tasks. Furthermore, forests see GIS (a computer based application) as an efficient management tool for their day –to-day operations.

A wide variety of software applications are available to support decision making in forest management, including databases, growth and yield models, wildlife models, silviculture expert systems, financial models, geographical information systems (GIS), and visualization tools (Schuster *et al*. 1993). Typically, each application has its own interface and data format, so managers must learn each interface and manually convert data from one format to another to use combinations of tools. Considering the scope of topics that may need to be addressed in a typical ecosystem management problem, and consequently the need to run several to many applications, manual orchestration of the entire analysis process can quickly become a significant impediment. Learning Management System (LMS) relieves this problem by managing the flow of information through predefined pathways that are programmed into its core component. LMS integrates landscape-level spatial information, stand-level inventory data, and distance independent individual tree-growth models to project changes on forested landscapes over time.

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. By selecting data with the appropriate spatial resolution, this assessment process can be used at any scale for planning agroforestry practices. The most significant benefit of using GIS-guided suitability assessments is the ability to combine different assessments to determine locations where multiple objectives can be achieved.

Suitability assessments have been used for several decades to identify locations for different land uses such as landfills, wildlife reserves, and residential development (McHarg 1995). Some of the first examples of suitability assessments in the United States were prepared by the Natural Resources Conservation Service (previously the Soil Conservation Service), which ranked soil types based on suitability for different engineering and agricultural functions (Soil Survey 1993). Although GIS and the suitability process have been used for many environmental protection applications, this technology has yet to be used extensively in agroforestry (Ellis *et al*. 2000, Bentrup & Leininger 2002).

Considering that GIS technology is widely available and affordable today and the fact that agroforestry is directly dependent upon spatial characteristics, it is logical to expect to have several agroforestry-specific GIS DSTs; but the reality is that only a few are available. An early GIS application compiled information on 173 species including their descriptions, soil and climate preferences, and management characteristics for Africa (Booth *et al*. 1989). This application allowed users to query the database and generate maps showing the climatic suitability for different species. At a regional scale, Booth *et al*. (1990) created a similar application for Zimbabwe, demonstrating how GIS applications can be done at many scales. Unruh & Lefebvre (1995) performed a similar GIS application for sub-Saharan Africa to determine areas suitable for different agroforestry systems. Integrating ICRAF's agroforestry database with spatial data on geographic regions, climate and land uses in the region, their application was able to map out potential regions for 21 specific types of agroforestry systems.

Most of the past agroforestry GIS applications mentioned above have been research-oriented. The Southeastern Agroforestry Decision Support System (SEADSS), developed recently 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). The USDA National Agroforestry Center (NAC) is currently using GIS to facilitate conservation buffer planning in the Western Corn Belt eco-region in the central United States (Bentrup *et al*. 2000). GIS guided assessments, derived from publicly available datasets, are being used to evaluate four key issues of the Western Cornbelt: 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). Utilizing the agroforestry product assessments (Bentrup & Leininger 2002) in conjunction with the riparian buffer connectivity assessments, areas were identified where riparian forest buffers could be located to improve habitat connectivity while offering landowners the option to grow woody floral for profit (Bentrup & Kellerman 2003). GIS-guided agroforestry suitability analysis will only improve as spatial data and computer resources become more accessible. Many states and countries already are assembling internet-accessible GIS data clearinghouses to facilitate the use of spatial information.

Information and technology transfer

Technical information must be developed locally or regionally for application within that region. Information which is too general or which is based on studies conducted in dissimilar regions or climate zones is not likely to convince landowners to adopt agro forestry practices, or provide relevant skills and knowledge to ensure their success. On-farm demonstrations and field days are keys to the understanding and appreciation of agro forestry practices by landowners. Education and training in agro forestry are needed both for natural resource professionals and college students.

In addition to the traditional model for the transfer of technology from researcher to extension agent to practitioner, landowners should have greater involvement in all phases of this process. With the assistance of research and extension personnel, local groups of landowners may analyse their own needs for agro forestry development, conduct on-farm experiments under real-life conditions, and then choose the practices most appropriate for their individual properties. Rather than accusing landowners of causing environmental degradation, they should be approached from a "win-win" perspective. Emphasis should be placed on participatory decision-making including landowner advisory groups. Research and information development should focus on agro forestry practices that afford economic opportunities, increase production efficiency, and provide cost-effective and pro-active solutions to conservation problems.

CONCLUSION AND FUTURE PROSPECTIVE

The relevance and application of information technology to Agro forestry practices in these days is of tremendous importance. There are still more areas where IT would be applicable in agroforestry which are yet to be discovered, but in the immediate future. Virtually, all other human endeavours have come to know that the benefits of IT is far outstripped its disadvantages. It is therefore suggested that IT should be a tool that all professions should embraced. Successful application of agroforestry systems depends upon pulling together diverse sources of information, in a manner that responds to users' needs and resources. Computer-based DSTs that accommodate these tasks can greatly facilitate the decision-making process that seeks to simultaneously balance environmental and production goals that meet landowner and societal needs. We must go beyond providing tools that only address the ecological and economic aspects of sustainability and provide those that also enhance the cultural sustainability of agroforestry systems; that is, it must elicit sustained human attention over time or else the benefits may be compromised as land ownership changes, as development pressure increases

REFERENCES

Baena M, Mejía M, Pineda B, Hidalgo R, Hesse H, Goldberg E & Amariles F (2007) *Delivering distance education on plant genetic resources*. Biodiversity International, Rome.

Bamgbade BJ & Oyeleye BO (2011) FRIN EJournal-An Electronic Submission Platform for Research Dissemination. *Proceeding of International Conference on ICT for Africa* 3: 243–250.

Bentrup G & Leininger T (2002) Agroforestry mapping: the way GIS. *Journal of Soil and Water Conservation* 57: 148–153.

Bentrup G & Leininger T (2002) Agroforestry: mapping the way with GIS. *Journal of Soil and Water Conservation* 57(6): 148a–152a.

Bentrup G, Dosskey M, Schoeneberger M, Wells M, Leininger T & Klenke K (2000) Planning for multi-purpose riparian management. In: Wigington PJ & Beschta RL (eds) *Riparian Ecology and Management in Multi-Land Use Watersheds*. American Water Resources Association, Middleburg, VA, pp. 423–426.

Booth TH, Stein JA, Hutchinson MF & Nix HA (1990) Identifying areas within a country climatically suitable for particular tree species: an example using Zimbabwe. *International Tree Crops Journal* 6: 1–16.

Booth TH, Stein JA, Nix HA & Hutchinson MF (1989) Mapping regions climatically suitable for particular species: an example using Africa. *Forest Ecology and Management* 28: 19–31.

DeMers MN (1997). *Fundamental of Geographic Information Systems*. Wiley, New York, 486 p.

Ellis EA, Nair PK, Linehan PE, Beck HW & Blanche CA (2000) A GIS-baseddatabase management application for agroforestry planning and tree selection. *Computers and Electronics in Agriculture* 27: 41–55.

Ellis EA, Nair PKR & Jeswani SD (2003) The southeastern agroforestry decision support system (SEADSS): A Web-based application for agroforestry planning and tree selection. In: Vacik H, Lexer MJ, Rauscher MH, Reynolds KM & Brooks RT (eds) *Decision Support for Multiple Purpose Forestry*. A Transdisciplinary Conference on the Development and Application of Decision Support Tools for Forest Management, University of Natural Resources and Applied Life Sciences, Vienna Austria, CD-ROM, pp. 1–12.

Grabaum R & Meyer B (1998) Multicriteria optimization of landscapes using GIS-based functional assessments. *Landscape and Urban Planning* 43: 21–34.

Guo Q (2000) Climate change and biodiversity conservation in the Great Plains. *Global Environmental Change* 10: 289–298.

Heathcote PM (2000) '*A' level ICT*. 2nd edition. Gallwaypublishers Ltd., pp. 1–11.

Lacher TE (1998) The spatial nature of conservation and development. In: Savitsky BG & Lacher TE (eds) *GIS Methodologies for Developing Conservation Strategies: Tropical Forest Recovery and Wildlife Management in Costa Rica*. Columbia University Press, New York, pp. 3–12.

McHarg I (1995) *Design with Nature*. John Wiley and Sons, New York, pp. 208.

Nair PKR (1998) Directions in tropical agroforestry research: past, present and future. *Agroforestry Systems* 38: 223–245

Nair PKR (2001) Agroforestry. In: *Our Fragile World: Challenges and Opportunities for Sustainable Development, Forerunner to The Encyclopedia of Life Support Systems*. UNESCO, Paris, France, & Eolss, UK, pp. 375–393.

Rhind DW (1988) A GIS research agenda. *International Journal of Geographical Information Systems* 2: 23–28.

Ruark GA, Schoeneberger MM & Nair PKR (2003) *Agroforestry - Helping to Achieve Sustainable Forest Management*. UNFF (United Nations Forum for Forests) Intercessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management. New Zealand, pp. 1–13.

Sanchez PA (1995) Science in agroforestry. *Agroforestry Systems* 30: 5– 55.

Schoeneberger M, Dix M & Dosskey M (1994) Agroforestry enhanced biodiversity: the good, the bad and the unknown. In: Rietveld W (ed) *Agroforestry and Sustainable Systems: Symposium Proceedings*. Fort Collins, CO. General Technical Report RM-GTR-261. US Department of Agriculture, Forest Service, Rocky Mountain Forest & Range Experiment Station, pp. 207–215.

Schuster EG, Leefers LA & Thompson JE (1993) *A guide to computer-based analytical tools for implementing national forest plans*. U.S.D.A. Forest Service, General Technical Report INT-296, pp. 269.

Soil Survey (1993) Soil Survey Manual. Natural Resources Conservation Service. U.S. Department of Agriculture, Handbook 18.

Unruh JD & Lefebvre PA (1995) A spatial database approach for estimating areas suitable for agroforestry in sub-Saharan Africa: aggregation and use of agroforestry case studies. *Agroforestry Systems* 32: 81–96.

Zeiler M (1999) *Modeling our World: the ESRI guide to geo database design*. ESRI Press. Redlands, CA., 199 p.