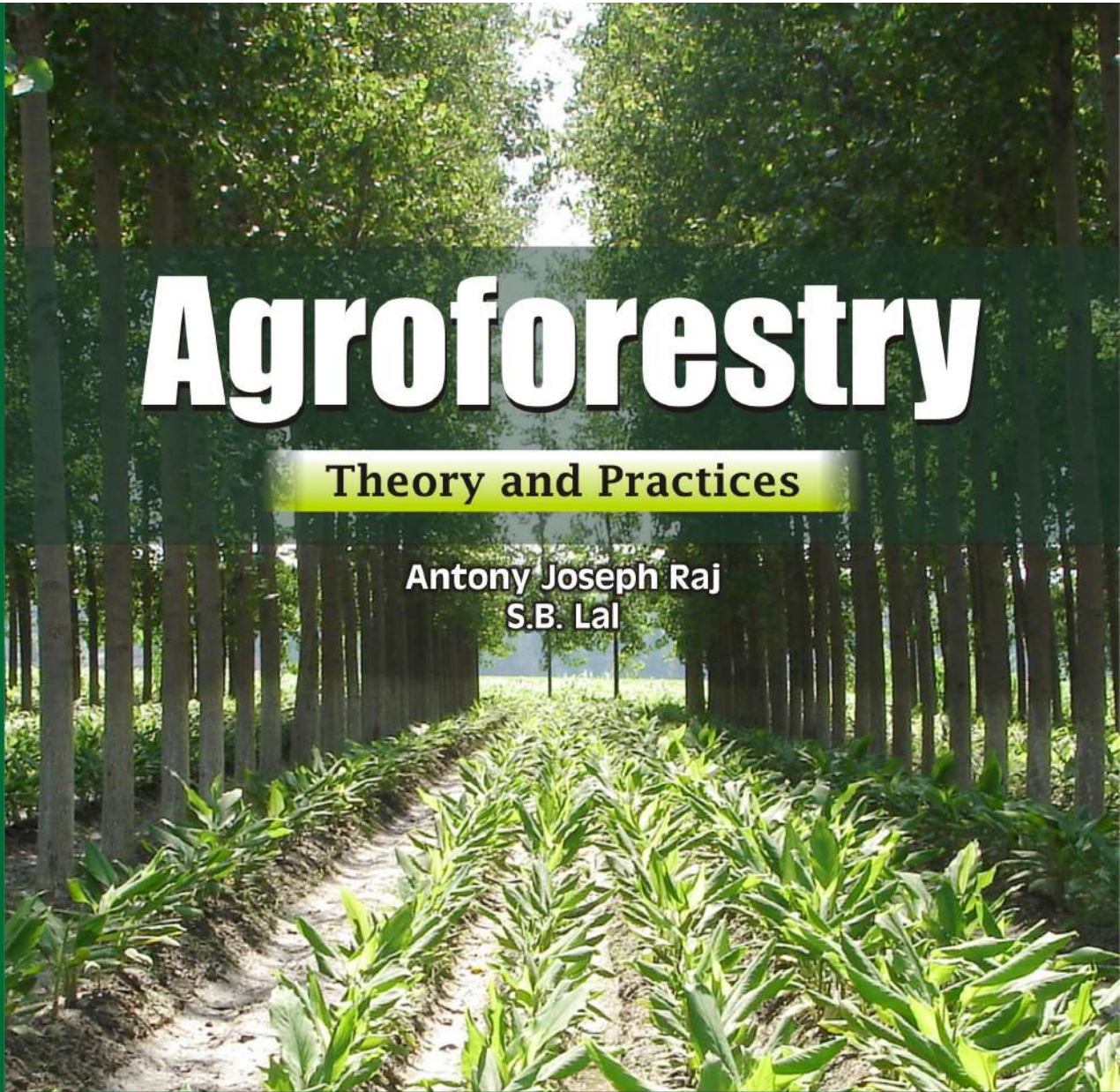


# Agroforestry

Theory and Practices

Antony Joseph Raj  
S.B. Lal



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S.B. Lal

**Agroforestry**  
*Theory and Practices*



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# AGROFORESTRY THEORY AND PRACTICES

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## FOREWORD

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World's total forest area is 4.03 billion hectares, corresponding to 31 per cent of the total land area or an average of 0.6 ha of per capita, whereas India's forest and tree cover is 78.29 million hectares which is only 23.81 per cent of the geographical area. We are continuously putting efforts to achieve the national goal of 33 per cent geographic area of the country under the forest and tree cover as enshrined in the National Forest Policy, 1988. India has only 2.4 per cent of the world's geographical area and 0.5 per cent of the world's grazing area but supports over 16 per cent of the world's human population and over 18 per cent of world's cattle population. This ever increasing population places enormous demands and pressures on the land resources and forest resources. Agroforestry is the potential option for increasing the tree cover outside the notified forest areas.

India is endowed with a variety of soils, climate, biodiversity and ecological regions. An area of 46.70 million ha has been estimated under wastelands which is 14.75 per cent of the total geographical area of the country. The land degradation issue threatens country's food security and the quality of the environment which assumes a major significance nowadays. Agroforestry practices are considered as most vital technology and potential farming system for minimizing the land degradation. Agroforestry practices increase farm productivity, diversify income sources for farmers and provide environmental services. Agroforestry improves soil, water and air quality, and biodiversity while supporting sustainable production of food, feed, fibre and energy. IPCC's prediction of temperature increase between 1.1°C and 6.2°C by the end of the century due to excessive carbon dioxide emission will most likely create extreme changes in temperature and precipitation. Agroforestry represents a significant opportunity for sequestering more carbon per unit area on agricultural lands and it can be better climate change mitigation option than ocean and other terrestrial options because of vast production and protective benefits.

The new comprehensive editorial textbook "Agroforestry: Theory and Practices" by Dr. Antony Joseph Raj and Prof. S.B. Lal is a rich source of knowledge and practical information on agroforestry drawn from the scientific literature, databases and field experiences from all over world. This textbook provides thoroughly up-to-date principles and methods on agroforestry and excellently covers the latest and modern technologies in

the agroforestry field. This book, with its high standards, will enormously benefit the students for their preparation of competitive exams like UPSC-Civil Services, UPSC-Indian Forest Service, ICAR-ARS Scientist Exam, ICFRE Forestry Scientist Exam, NET Exam, State Public Service Commission Exams etc. I am confident that scientists, University and college teachers, and foresters from all over world should find this resource book useful in creating effective and innovative training programmes and manpower in agroforestry.

I welcome this latest Agroforestry textbook which will be most valuable to the students of agriculture, forestry, horticulture, soil science, water science, ecology, environment science and other plant sciences.

I would like to congratulate the authors, Dr. Antony Joseph Raj and Prof.S.B.Lal, for their tireless efforts in bringing this high quality textbook for the benefit of students, teachers, scientists and agricultural community.



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July 2013

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## PREFACE

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Agroforestry provides a different land use option, compared with traditional agricultural and forestry systems. Agroforestry combines trees, shrubs, forages, grasses, livestock, and crops in innovative, flexible combinations tailored to the needs of farmers and landowners. This intensive integration in agroforestry ensures sustained availability of multiple products as direct benefits such as food, vegetables, fruits, fodder, fuel, manure, medicine, timber, etc. It makes use of the complementarity between trees and crops, so that the available resources can be more effectively exploited. It is a practice that respects the environment and has an obvious landscape benefit. The integration of trees, agricultural crops, and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics and sequester carbon. Efficient, modern versions of agroforestry have been developed around the world which can be adapted to different agroclimatic conditions.

The agroforestry always remains productive for the farmer and generates continuous revenue. Agroforestry allows for the diversification of farm activity and makes better use of environmental resources. The goal of agroforestry is to optimize productivity and conservation benefits within a set of integrated land use practices. Agroforestry has interesting advantages from three different perspectives viz. agriculture, forestry and environment. The agroforestry practices enhance biodiversity, sequester more carbon dioxide from atmosphere, diversify farmers' income sources, generate greater profits than annual crops, and create a more integrated, interesting, and visually appealing land use system that may be more environmentally, economically, and socially sustainable than the original farmland. With the shrinking per capita land availability, agroforestry system with the integration of perennial woody trees with crops/pastures is most suitable technology for increasing total productivity of food, feed and fuel and thereby reducing the risk of farming.

This editorial textbook "Agroforestry: Theory and Practices" is one of the finest books on agroforestry that offers a global review of the basic approaches, tools and technologies, research innovations and real-world practices in agroforestry. The book offers a comprehensive guide to basic principles, techniques and applications, integrative strategies, economic and environmental concerns, and future trends in agroforestry in

different regions of the world. This textbook is an effort to create a coherent and wide-ranging guide to the practice of agroforestry. This book covers key areas in agroforestry, namely agroforestry practices and its distribution, agroforestry systems classification, agroforestry trees, agroforestry management, technologies and modern concepts in agroforestry, production benefits of agroforestry, environmental services of agroforestry, agroforestry education, research & extension, etc.

In many aspects, the topics and structure of this textbook is highly meritorious and unique than other agroforestry books. This textbook is intended for university & college students, professors, scientists, researchers, foresters, farmers, policy makers and professionals in the field of agriculture, forestry, horticulture, other agricultural sciences and biological sciences. The main intention of this textbook is to provide a state-of-the-art and up-to-date knowledge of recent developments in agroforestry as a potential future land use system. This textbook on agroforestry will enormously benefit the students for their preparation of competitive exams like UPSC-Civil Services, UPSC-Indian Forest Service, ICAR-ARS Scientist/NET Exam, ICFRE Forestry Scientist Exam, State Public Service Commission Exams and University Entrance Exam for admission to M.Sc. and Ph.D. programmes

This agroforestry textbook will contribute significantly to academic teaching and scientific research. Additional information or suggestions are invited from experienced researchers and experts for improving the quality of the book in future editions. We thank Dr.(Mrs.) Roselin Antony, Assistant Professor of Mekelle University (Ethiopia) for her editorial help and for enhancing the English language & technical writing of manuscript. We are confident that this agroforestry textbook will become a huge success just like our earlier book “Forestry: Principles and Applications”.

**ANTONY JOSEPH RAJ**  
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July 2013

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## ABBREVIATIONS AND ACRONYMS

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|                        |  |
|------------------------|--|
| A&R                    | : Afforestation and Reforestation  |
| ACIAR                  | : Australian Centre for International Agricultural Research                        |
| AEZs                   | : Agro-Ecological Zones  |
| AF                     | : Agroforestry   |
| AFLP                   | : Amplified Fragment Length Polymorphism   |
| AFNETA                 | : Alley Farming Network for Tropical Africa  |
| AFRENA                 | : African Research Network on Agroforestry   |
| AFS                    | : Agroforestry System  |
| AFTA                   | : Association for Temperate Agroforestry   |
| AFTPs                  | : Agroforestry Tree Products   |
| AGB                    | : Aboveground Biomass  |
| AICRP                  | : All India Coordinated Research Project   |
| AICRP-<br>Agroforestry | : All India Coordinated Research Project on Agroforestry                           |
| AIDAB                  | : Australian International Development Assistance Bureau                           |
| ANAFE                  | : African Network for Agriculture, Agroforestry and Natural Resources<br>Education |
| APAN                   | : Asia-Pacific Agroforestry Network  |
| ASB                    | : Alternatives to Slash-and-Burn   |
| B/C Ratio              | : Benefit/Cost Ratio   |
| BCTIO                  | : British Columbia Trade and Investment Office                                     |
| BNF                    | : Biological Nitrogen Fixation   |
| CA                     | : Conservation Agriculture   |
| CAF                    | : Complex Agroforestry Systems   |
| CAMCORE                | : Central American and Mexico Coniferous Resources Cooperative                     |
| CAPS                   | : Cleaved Amplified Polymorphic Sequences  |

|             |   |
|-------------|---|
| CBD         | : Convention on Biological Diversity  |
| CDIAC       | : Carbon Dioxide Information Analysis Center  |
| CEC         | : Cation Exchange Capacity  |
| CFA         | : Commonwealth Forestry Association   |
| CFCs        | : Chlorofluorocarbons   |
| CGIAR       | : Consultative Group on International Agricultural Research                           |
| CIAT        | : International Center for Tropical Agriculture                                       |
| CIDA        | : Canadian International Development Agency   |
| CIFOR       | : Centre for International Forestry Research  |
| CIRAD-Forêt | : Centre de coopération internationale en recherche agronomique pour le développement |
| COP         | : Conference of the Parties   |
| CPR         | : Common Property Resources   |
| CRD         | : Completely Randomized Design  |
| CSIRO       | : Commonwealth Scientific and Industrial Research Organization                        |
| CSSRI       | : Central Soil Salinity Research Institute  |
| CSTAF       | : Center for Subtropical Agroforestry   |
| CSWCRTI     | : Central Soil and Water Conservation Research and Training Institute                 |
| D&D         | : Diagnosis and Design  |
| DANIDA      | : Danish International Development Agency   |
| DBH         | : Diameter at Breast Height   |
| DoLR        | : Department of Land Resources  |
| EAI         | : Equivalent Annual Income  |
| EFI         | : European Forest Institute   |
| ESP         | : Exchangeable Sodium Percent   |
| ESTs        | : Expressed Sequence Tags   |
| ET          | : Evapotranspiration  |
| ETFRN       | : European Tropical Forest Research Network   |
| EURAF       | : European Agroforestry Federation  |
| FACT Net    | : Forest, Farm, and Community Tree Network  |
| FAO         | : Food and Agricultural Organization of the United Nations                            |
| FARA        | : Forum for Agricultural Research in Africa   |
| FDC         | : Forest Development Corporation  |
| FGNFTs      | : Fast Growing Nitrogen Fixing Trees  |
| FINNIDA     | : Finnish International Development Agency  |
| FIO         | : Forest Industries Organization  |

|         |   |
|---------|---|
| FRIM    | : Forest Research Institute Malaysia  |
| FSR/E   | : Farming Systems Research/Extension  |
| FYM     | : Farm Yard Manure  |
| GDP     | : Gross Domestic Product  |
| GEF     | : Global Environment Facility   |
| GHGs    | : Greenhouse Gases  |
| GIS     | : Geographic Information System   |
| GPP     | : Gross Primary Production  |
| Gt      | : Gigaton   |
| GTZ     | : Deutsche Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation) |
| GWP     | : Global Warming Potential  |
| HCFCs   | : Hydrochlorofluorocarbons  |
| HDSR    | : High Density Short Rotation   |
| HFCs    | : Hydrofluorocarbons  |
| IAASTD  | : International Assessment of Agricultural Knowledge, Science and Technology for Development    |
| IARCs   | : International Agricultural Research Centers   |
| IBPGR   | : International Board for Plant Genetic Resources   |
| ICAR    | : Indian Council of Agricultural Research   |
| ICARDA  | : International Center for Agricultural Research in the Dry Area                                |
| ICEF    | : India-Canada Environment Facility   |
| ICFRE   | : Indian Council of Forestry Research and Education   |
| ICRAF   | : International Centre for Research in Agroforestry (World Agroforestry Centre)                 |
| ICRISAT | : International Crops Research Institute for the Semi-Arid Tropics                              |
| IDRC    | : International Development Research Centre   |
| IFPRI   | : International Food Policy Research Institute  |
| IFS     | : Integrated Farming System   |
| IGNFA   | : Indira Gandhi National Forest Academy   |
| IIED    | : International Institute for Environment and Development                                       |
| IIFS    | : Intensive Integrated Farming System   |
| IIRR    | : International Institute of Rural Reconstruction   |
| IISD    | : International Institute for Sustainable Development   |
| IITA    | : International Institute of Tropical Agriculture   |
| IITF    | : International Institute of Tropical Forestry  |
| ILCA    | : International Livestock Centre for Africa   |

|        |  |
|--------|--|
| ILRI   | : International Livestock Research Institute           |
| INBAR  | : International Network for Bamboo and Rattan          |
| INM    | : Integrated Nutrient Management                       |
| IPCC   | : Intergovernmental Panel on Climate Change            |
| IPM    | : Integrated Pest Management                           |
| IPNS   | : Integrated Plant Nutrition Systems                   |
| IRR    | : Internal Rate of Return                              |
| ISTC   | : International Standard Trade Classification          |
| IUCN   | : International Union for Conservation of Nature       |
| IUFRO  | : International Union of Forest Research Organizations |
| JFMC   | : Joint Forest Management Committees                   |
| KVK    | : Krishi Vigyan Kendra                                 |
| LAMPS  | : Large-Area Multipurpose Societies                    |
| LEV    | : Land Expectation Value                               |
| LKTS   | : Lesser Known Tree Species                            |
| LPG    | : Length of Growing Period                             |
| LSD    | : Latin Square Design                                  |
| LULUCF | : Land-Use, Land-Use Change and Forestry               |
| LUS    | : Land Use System                                      |
| MAF    | : Multistoried Agroforestry System                     |
| MAPs   | : Medicinal and Aromatic Plants                        |
| MAS    | : Marker Assisted Selection                            |
| MDGs   | : Millennium Development Goals                         |
| MFPF   | : Minor Forest Produce Federation                      |
| Mha    | : Million Hectare                                      |
| MPTs   | : Multipurpose Trees                                   |
| MPTS   | : Multipurpose Trees and Shrubs                        |
| MT     | : Million Tons   |
| MTS    | : Modified Taungya System                              |
| MUSLE  | : Modified Universal Soil Loss Equation                |
| MW     | : Mega Watt  |
| NAPCD  | : National Action Programme to Combat Desertification  |
| NASA   | : National Aeronautics and Space Administration        |
| NBM    | : National Bamboo Mission                              |
| NBP    | : Net Biome Production                                 |
| NBPGR  | : National Bureau of Plant Genetic Resources           |

|       |  |
|-------|--|
| NEP   | : Net Ecosystem Production                                     |
| NEPED | : Nagaland Environment Protection and Economic Development     |
| NFAP  | : National Forestry Action Programme                           |
| NFP   | : National Forest Policy                                       |
| NFTA  | : Nitrogen Fixing Tree Association                             |
| NFTs  | : Nitrogen Fixing Trees  |
| NPP   | : Net Primary Production                                       |
| NPV   | : Nuclear Polyhedrosis Virus                                   |
| NPV   | : Net Present Value  |
| NRCAF | : National Research Centre for Agroforestry                    |
| NRM   | : Natural Resource Management                                  |
| NRSA  | : National Remote Sensing Agency                               |
| NRSC  | : National Remote Sensing Centre                               |
| NTFPs | : Non-Timber Forest Products                                   |
| NWDB  | : National Wasteland Development Board                         |
| NWFPs | : Non-Wood Forest Products                                     |
| NWTPs | : Non-Wood Tree Products                                       |
| OFI   | : Oxford Forestry Institute                                    |
| PAGR  | : Plant and Animal Genetic Resources                           |
| PFCs  | : Perfluorocarbons   |
| Pg    | : Pentagon   |
| PGR   | : Plant Genetic Resources                                      |
| ppm   | : Parts Per Million  |
| QTL   | : Quantitative Trait Loci                                      |
| RaCSA | : Rapid Carbon Stock Appraisal                                 |
| RAPD  | : Random Amplified Polymorphic DNA                             |
| RBD   | : Randomized Block Design                                      |
| RCBD  | : Randomized Complete Block Design                             |
| REDD  | : Reducing Emissions from Deforestation and forest Degradation |
| RFLP  | : Restriction Fragment Length Polymorphism                     |
| RH    | : Relative Humidity  |
| ROR   | : Rate of Return   |
| SAC   | : Space Application Centre                                     |
| SAF   | : Simple Agroforestry Systems                                  |
| SALT  | : Sloping Agricultural Land Technology                         |
| SALWA | : Semi-Arid Lowlands of West Africa                            |

|          |  |
|----------|--|
| SAR      | : Sodium Adsorption Ratio  |
| SAT      | : Semi-Arid Tropics  |
| SEANAFE  | : Southeast Asian Network for Agroforestry Education                     |
| SFCs     | : State Forest Corporations  |
| SFR      | : Short Rotation Forestry  |
| SFRC     | : Southern Forest Rangers College  |
| SIDA     | : Swedish International Development Agency                               |
| SLM      | : Sustainable Land Management  |
| SNPs     | : Single Nucleotide Polymorphisms  |
| SOC      | : Soil Organic Carbon  |
| SOM      | : Soil Organic Matter  |
| SPWD     | : Society for Promotion Wasteland Development                            |
| SSRs     | : Simple Sequence Repeats  |
| SWEET    | : Sloping Watershed and Environmental Engineering Technology             |
| TAF CORN | : Tamil Nadu Forest Plantation Corporation                               |
| TAI      | : Tree-Animal Interface or Tree-Animal Interaction                       |
| TBOs     | : Tree Borne Oil Seeds   |
| TCI      | : Tree-Crop Interface or Tree-Crop Interaction                           |
| TDC      | : Tribal Development Corporation   |
| TDP      | : Tree Domestication Program   |
| TLC      | : Total Literacy Campaign  |
| TOF      | : Trees Outside Forests  |
| UMCA     | : University of Missouri Center for Agroforestry                         |
| UNCBD    | : United Nations Convention on Biological Diversity                      |
| UNCCD    | : United Nations Convention to Combat Desertification                    |
| UNCED    | : United Nations Conference on Environment and Development               |
| UNDP     | : United Nations Development Programme                                   |
| UNEP     | : United Nations Environment Programme                                   |
| UNFCCC   | : United Nations Framework Convention on Climate Change                  |
| UNICEF   | : United Nations Children's Fund   |
| USDA-NAC | : United States Department of Agriculture – National Agroforestry Center |
| USLE     | : Universal Soil Loss Equation   |
| VFC      | : Village Forest Committees  |
| VOCs     | : Volatile Organic Compounds   |
| VVK      | : Van Vigyan Kendra  |
| WBG      | : World Bank Group   |

WEHAB : Water, Energy, Health, Agriculture and Biodiversity Initiative

WMO : World Meteorological Organization

# Agroforestry

Theory and Practices

**Antony Joseph Raj & S.B. Lal**

Agroforestry is practiced by millions of farmers, and has been a feature of agriculture for millennia. Agroforestry is the only land use system able to solve global issues such as climate change, biodiversity conservation, decreasing soil health and quality of land resources, energy and economic crises, food security and poverty eradication, etc. and application of agroforestry innovations will help to attain Millennium Development Goals (MDGs). This textbook is one of the finest books on agroforestry that offers a global review of the approaches, tools and technologies, research innovations and real-world practices in agroforestry. The book offers a comprehensive guide to basic principles, techniques and applications, integrative strategies, economic and environmental concerns, and future trends in agroforestry in different regions of the world. It will help all scientists, students, professors, farmers, foresters, decision-makers, and politicians who wish to build a safe land use system for food, energy and better environment for future generations. This textbook will enormously benefit the students for their preparation of competitive exams like UPSC-Civil Services, UPSC-Indian Forest Service, ICAR-ARS Scientist/NET Exam, ICFRE Forestry Scientist Exam, State Public Service Commission Exams and University Entrance Exam for admission to M.Sc. and Ph.D. programmes.

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