

Agroforestry based farming system

for boosting farmers' income

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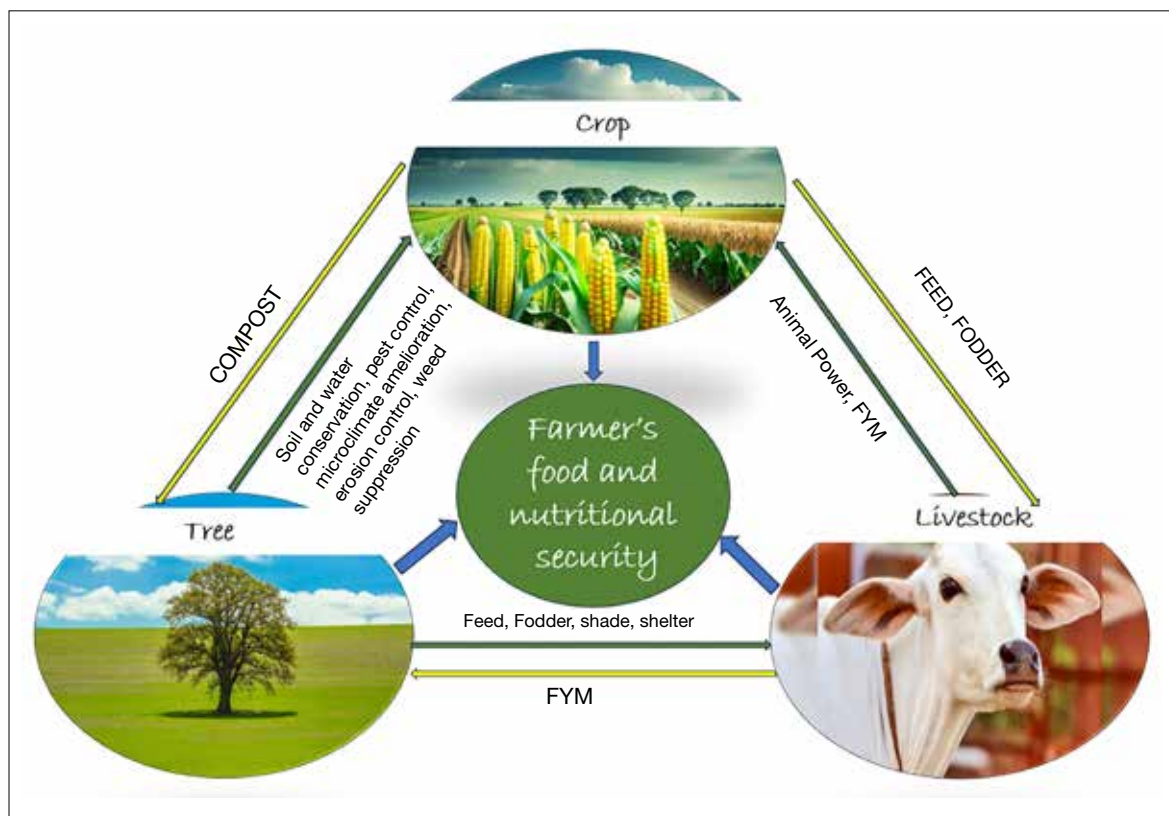
Indian agriculture has evolved significantly, but unsustainable practices (intensive cultivation, mono-cropping, high external input uses, over exploitation of natural resources) threaten long-term productivity and environmental health. Conservation-focused integrated farming systems (IFS) and agroforestry are pivotal for addressing challenges like climate change, resource degradation, and food security. By integrating trees, crops, and livestock, these systems enhance soil fertility, sequester carbon, and promote biodiversity while diversifying farmers' income. Examples from various agro-climatic zones illustrate their adaptability and economic viability. Agroforestry reduces dependence on external inputs, mitigates climate risks, and fosters ecological resilience. Scaling such sustainable models through research and adoption is critical for ensuring agricultural productivity, environmental conservation, and food security for future generations.

Keywords: Agroforestry, Bundelkhand region, Integrated farming system

INDIAN agriculture has undergone a remarkable transformation, evolving from subsistence farming to becoming one of the world's leading agricultural producers. This progress has been driven by the Green Revolution, advancements in irrigation, mechanization, and adopting high-yielding crop varieties. However, this rapid agricultural expansion has come at a significant cost to natural resources. Unsustainable practices such as excessive groundwater extraction, overuse of chemical fertilizers and pesticides, and the focus on water-intensive mono-cropping systems like rice and wheat have led to severe resource degradation. The consequences include declining soil fertility, groundwater depletion, biodiversity loss, and widespread land degradation. Moreover, these practices have made agriculture more vulnerable to the impacts of climate change, threatening long-term productivity and environmental health. In India more than 85% of the farming household have less than two hectares of land who face challenges of frequent crop failure due to weather aberrations. According to the International Food Policy Research Institute (IFPRI), projections indicate that by 2030, India's food production could decline by 16%, with a 23% rise in the number of people at risk of hunger, due to climate change. These alarming statistics

carry significant implications for global food security, given India's pivotal role in agricultural production and its contribution to the global food supply. This underscores the urgent need to adopt sustainable agricultural practices that enhance productivity, conserve natural resources, and build resilience to climate change to ensure food security for future generations. Additionally, small and marginal farmers are not able to invest in modern farming because of less investment and risk-taking capacity. In order to address the different needs of farmers and to minimize the risk against climate change, various Integrated Farming System models have been developed in different agroclimatic regions of the country. In comparison to cropping alone, integrated farming system and agroforestry have been proved to be more productive, due to low risk of failure and high net profit.

Integrating multiple components such as crops, livestock and fisheries into a single farm unit has long emerged as a pivotal solution to ensure agricultural security and sustainability. This approach not only enhances farm productivity but also diversifies income sources, reduces risks from climate variability, and improves soil health through natural nutrient recycling. Moreover, integrating agroforestry into the



Generalized framework showing the nexus among trees, crops, and livestock for farmer food and nutritional security

IFS framework provides a lot of benefits including carbon sequestration, improved water retention, and enhanced biodiversity. Together, these systems can help India address its twin challenges of food security and environmental degradation. These systems offer a sustainable pathway to conserve resources while meeting the growing food demands of a burgeoning population. By aligning agricultural practices with ecological principles, India can secure long-term agricultural productivity, ensure the well-being of its farmers, and contribute to global efforts for sustainable development.

Tree-crop-livestock nexus for sustainable benefits

Integrated farming systems can include agroforestry systems, which combines trees with crops or cattle that can increase soil fertility, store carbon dioxide, and provide additional revenue. The tree component in the triangle provides numerous benefits to livestock (feed, fodder, shade and shelter) and crop component (soil conservation, water conservation, regulation of microclimate, weed suppression, pest control, carbon sequestration, climate mitigation, and reduced dependence on external inputs). The crop and livestock in turn provide compost and FYM to trees respectively. The crop component in the agroforestry system provides feed, and fodder to livestock however the livestock component in return provides animal power and FYM to the other two components. Therefore, this nexus among the three components indicates the symbiotic or positive interrelation which indicates that agroforestry is a sustainable practice for getting better production

and economic return to the farmers compared to mono-cropping. Among the three pillars of agroforestry, i.e. Tree, crop, and livestock, the farmers can get food grains, vegetables, pulses, oil, from the crop component, fruit, gum, medicines from the tree component, and milk, meat from the livestock component. The diverse nature of the agroforestry system provides more food and nutritional security to the farmers compared to the mono-cropping system.

Various ways to integrate trees into the farming system

Agroforestry, practiced by millions of farmers, has been an integral part of Indian agriculture for millennia. The ICAR-Central Agroforestry Research Institute, Jhansi and the All India Coordinated Research Program on Agroforestry (AICRP-AF) work actively with farmers to develop and enhance diverse agroforestry systems. Trees can be incorporated into farming systems in various ways to maximize the benefits of tree-crop-livestock interactions. Key factors such as utility, climatic adaptability, root architecture, compatibility with crops, and canopy characteristics serve as essential criteria for selecting tree species for integration into farming systems. Table 1 highlights prominent agroforestry systems across different agro-climatic zones in India, showcasing their adaptability and benefits.

Benefits of tree integration in the farming system

By integrating trees with farming system create diverse and dynamic landscapes that give various benefits (ecological, economic and social) to the society.

Table 1. Prominent agroforestry systems in different agroclimatic zones of India

Agro-climatic Zone	Agroforestry systems	Tree component	Crop/Grass
Western Himalayas	Silvipasture (RF)	<i>Grewia optiva</i>	<i>Setaria</i> spp.
		<i>Morus alba</i>	<i>Setaria</i> spp.
	Agri-silviculture	<i>Grewia optiva</i>	Rice, beans
	Agri-horticulture and Hortipasture	<i>Malus pumila, Juglans regia</i>	Millets, Wheat, <i>Trifolium repense, Dactylis glomerata, Trifolium alexandrium</i>
Eastern Himalayas	Agri-horticulture	<i>Prunus persica</i>	Maize, Soybean, Vegetables
	Agri-silviculture	<i>Anthocephalus cadamba, Bamboo</i>	Rice, pulses
	Agri-horticulture	<i>Alnus nepalensis, Morus alba</i>	Large Cardamom/Coffee, Rice, wheat, vegetables
Lower Gangetic Plains	Silvipasture	Bamboo, <i>Parkia roxburghii, Morus alba</i>	<i>Digitaria decumbens, Cenchrus ciliaris, Dactylis glomerata</i> and <i>Dicanthium annualatum</i>
	Silvipasture	<i>Bauhinia variegata, Ficus</i> spp., <i>Morus alba</i>	Napier
	Agri-silviculture	<i>Dalbergia sissoo, Bombax ceiba, Tectona grandis, Ziziphus jujuba</i>	Wheat, Maize, Paddy
	Agri-horti-silviculture	<i>Mangifera indica, Terminalia arjuna, Morus alba, Litchi chinensis, Emblica officinalis</i>	Wheat, Maize, Paddy
	Silvi-agriculture	<i>Cassia fistula, Bombax ceiba</i>	Wheat, Maize, Paddy
	Homestead	<i>Azadirachta indica, Dalbergia sissoo, Mango, Jackfruit, Litchi, Guava, Emblica officinalis</i>	Ginger, Turmeric
	Silvi-pastoral	<i>Dalbergia sissoo, Acacia nilotica</i>	Maize (fodder), Local grass
	Farm Boundary	<i>Dalbergia sissoo, Wendanlandia exerta</i>	Wheat, Gram, Rajmah, Castor
	Shelterbelt	<i>Dalbergia sissoo, Dendrocalamus strictus</i>	Wheat, Maize, Paddy
	Homestead	<i>Azadirachta indica, Dalbergia sissoo, Leucaena leucocephala, Mango, Jackfruit, Guava, Bael, Ber</i>	Vegetables, Ginger, Turmeric
Middle Gangetic Plains	Agri-silviculture	<i>Azadirachta indica, Dalbergia sissoo, Mangifera indica, Psidium guajava, Zizyphus mauritiana, Albizia lebbbeck</i>	Rice, Wheat
	Farm boundary	<i>Acacia nilotica, Prosopis juliflora, Eucalyptus</i> spp., <i>Ficus religiosa, Acacia catechu, Madhuca latifolia, Bamboo</i> spp.	Rice-Wheat
	Agri-horti-silviculture	<i>Dalbergia sissoo, Mango, Guava</i>	Vegetables, Wheat
	Farm Boundary	<i>Dalbergia sissoo, Eucalyptus</i> sp.	Rice, Wheat
	Homestead	<i>Madhuca latifolia, Dalbergia sissoo, Azadirachta indica, Bamboo, Syzygium cuminii, Ficus</i> sp., Mango, Guava	Vegetables, Wheat, Ginger, Turmeric
Trans Gangetic Plains	Agri-silviculture	<i>Azadirachta indica, Dalbergia sissoo, Acacia nilotica, Mango</i>	Rice, Wheat
	Horti-silviculture	<i>Populus deltoides, Mangifera indica, Emblica officinalis, Psidium guajava, Aegle marmelos</i>	
	Block Plantation	<i>Eucalyptus</i> hybrid, <i>Populus deltoides</i>	
Upper Gangetic Plains	Farm Boundary	<i>Eucalyptus</i> hybrid, <i>Populus deltoides</i>	
	Agri-silviculture	<i>Acacia nilotica, Dalbergia sissoo, Acacia catechu, Ziziphus</i> sp., <i>Butea monosperma, Grewia optiva</i>	Pearl millet, Sorghum, Sunflower, Sugarcane
	Farm boundary	<i>Populus deltoides, Eucalyptus</i> spp.	Rice, Wheat, Cotton, Potato
	Agri-silviculture	<i>Populus deltoides</i>	Rice, Wheat, Potato, Sunflower, Sugarcane
	Agri-horticulture	<i>Mango, Citrus, Litchi, Ber</i>	Rice, Wheat, Potato, Sunflower, Sugarcane
	Farm Boundary	<i>Eucalyptus</i> hybrid, <i>Populus deltoides</i>	Rice, Wheat, Potato, Sunflower, Sugarcane
	Scattered trees	<i>Prosopis cineraria, Acacia nilotica, Acacia tortilis, Dalbergia sissoo</i>	Pearl, millet, Sorghum, Sunflower

Agro-climatic Zone	Agroforestry systems	Tree component	Crop/Grass
Eastern Plateau and Hills	Agri-silviculture	<i>Gmelina arborea</i>	Rice, Linseed
	Agri-silviculture	<i>Acacia nilotica</i>	Rice
	Silvipasture	<i>Acacia mangium</i> , <i>A. nilotica</i> , Bamboo	-
	Silvipasture	<i>Leucaena leucocephala</i>	<i>Chrysopogon</i> , <i>Pennisetum</i> , <i>Dicanthium</i>
Central Plateau and Hills	Agri-horticulture (Irri)	<i>Psidium guajava</i>	Bengal Gram/Groundnut
	Agri-horticulture (RF)	<i>Embliba officinalis</i>	Black gram/Green gram
	Agri-silviculture	<i>Acacia nilotica</i> / <i>Leucaena leucocephala</i> / <i>Azadirachta indica</i> / <i>Albizia lebbeck</i>	Soybean, Black gram-Mustard/Wheat
	Silvipasture (RF- and degraded lands)	<i>Albizia amara</i> , <i>Leucaena leucocephala</i> , <i>Dichrostyculus cinerea</i>	<i>Chrysopogon</i> , <i>Stylosanthes hamata</i> , <i>S. scabra</i>
	TBOs (RF)	<i>Jatropha curcas</i>	-
Western Plateau and Hills	Agri-horti-silviculture (Irri)	<i>Tectona grandis</i> , <i>Achras zapot</i>	Rice, Maize
	Agri-horticulture	<i>Areca catechu</i>	Black pepper, Cardamom
	Silviculture	<i>Prosopis juliflora</i> , <i>Ailanthus excels</i>	-
	Silvipasture	<i>Acacia mangium</i> , <i>Albizia amara</i>	<i>Cenchrus</i>
Southern Plateau and Hills	Agri-silviculture (RF)	<i>Eucalyptus</i> , <i>Casuarina equisetifolia</i> , <i>Ailanthus excelsa</i>	Cotton, Groundnut
	Agri-silviculture (Irri)	<i>Eucalyptus tereticornis</i> , <i>Melia dubia</i>	Chilli
	Silviculture (RF)	<i>Leucaena leucocephala</i> , <i>Acacia leucopholea</i>	-
		<i>Eucalyptus</i>	-
	Agri-horticulture	<i>Tamarindus indica</i>	Chilli
East Coast Plains and Hills	TBOs	<i>Pongamia pinnata</i>	-
	Agri-silviculture	<i>Ailanthus excelsa</i> , <i>Acacia leucophloea</i>	Cow pea
	Silviculture	<i>Casuarina equisetifolia</i> , <i>Leucaena leucocephala</i>	-
	TBOs	<i>Pongamia pinnata</i>	-
	Silvipasture	<i>Artocarpus</i> spp.	<i>Chrysopogon</i> , <i>Napier</i> , <i>Cenchrus</i>
West Coast Plains and Hills	Agri-silviculture	<i>Acacia auriculiformis</i>	Black Pepper
	Agri-horticulture	<i>Artocarpus heterophyllus</i> , <i>Cocos nucifera</i> / <i>Areca catechu</i>	Black Pepper, Rice, Cassava
	Agri-silviculture	<i>Acacia auriculiformis</i>	Rice
	Agri-silviculture	<i>Casuarina equisetifolia</i>	Rice
	Silvipasture	<i>Hardwickia binnata</i> , <i>Albizia lebbeck</i>	<i>Cenchrus</i>
Gujarat Coast Plains and Hills	Agri-silviculture	<i>Ailanthus excelsa</i> , <i>Tectona grandis</i> , <i>Azadirachta indica</i> , <i>Eucalyptus</i> , <i>Casuarina</i>	Cowpea, Greengram, Wheat, Vegetables
	Silviculture	<i>Acacia nilotica</i> , <i>Eucalyptus</i> , Bamboo	-
	Silvipasture	<i>Leucaena leucocephala</i>	<i>Cenchrus</i> , <i>Setaria</i> ,
	Agrihorticulture	<i>Mangifera indica</i> (Mango), <i>Manilkara zapota</i> (Sapota), <i>Zizyphus mauritiana</i> (Ber), Custard apple, Drumstick, Aonla	Cowpea, Greengram, Wheat, Vegetables
Western Dry Region	Agri-silviculture	<i>Prosopis cineraria</i> , <i>Tecomella indica</i> , <i>Acacia nilotica</i> , <i>Azadirachta indica</i>	Pearl millet, Fodder sorghum, Mungbean, Mothbean, Cowpea, Guar
	Silvipasture	<i>Albizia lebbeck</i> , <i>Hardwickia binnata</i> , <i>Prosopis cineraria</i>	<i>Cenchrus ciliaris</i> , <i>Cenchrus setigerus</i> , <i>Lasiurus indicus</i> , <i>Dichanthium annulatum</i> , <i>Panicum antidotale</i> and <i>Sehima nervosum</i>
	Agri-horti-pasture	<i>Citrus</i> , <i>Ber</i>	Mungbean, Moth bean, Guar, Grasses
All Islands	Agri-horticulture	<i>Cocos nucifera</i>	Rice
	Silvipasture	<i>Albizia amara</i> , <i>Bauhinia</i> spp, <i>Erythrina indica</i> , <i>Leucaena leucocephala</i>	<i>Cenchrus</i> , <i>Pennisetum</i>

Source: Ram et al. (2023)



Multifaceted benefits form tree integration in the farming system

The different benefits of tree integration are described below.

A trailblazer in agroforestry: A woman farmer's success in Banda district

A woman farmer Mrs. Santosh Singh from Manipur village in Banda District has successfully transformed her 2-hectare farmland by adopting an agroforestry-based farming system. Motivated by challenges such as poor crop productivity and losses caused by erratic weather conditions, she decided to incorporate agroforestry practices into her agricultural efforts. Ten years ago, she planted a diverse range of trees, including mango (Dashahari, Malihabadi, Amrapali, Safeda, and Ramkela), guava (L-49, Lalit, Sweta, and Pink Taiwan), lemon, moringa, Malabar neem, karonda, teak, jackfruit, mulberry, and dragon fruit. Today, her

farm boasts 956 trees of various agroforestry species. In addition to cultivating trees, she has been growing kharif and rabi crops in the interspaces between tree rows, maximizing the productive use of her land. For household needs, she rears a desi-breed cow and two goats. Her diversified farming system has not only proven to be resilient to climatic fluctuations but also generated an annual income of approximately ₹2.50 lakh from the sale of fruits and crops. Her efforts have been greatly supported by her son, Mr. Alok Singh, who has actively contributed to transforming their land use and advancing their diversified farming approach. The district administration of Banda has recognized her remarkable success, which stands as an inspiring example of sustainable and innovative farming practices. Her journey demonstrates the immense potential of agroforestry to empower farmers and create resilient



agricultural systems.



Table 2. Financial analysis of different agroforestry systems in India



System	Gross return (₹)	Net return (₹)	B: C Ratio	References
Agri-silviculture	1,04,575	53,975	2.07	Yadav <i>et al.</i> (2018)
Agri-horticulture	3,01,823	1,82,163	2.53	
Agri-horti-silviculture	2,79,801	1,63,945	2.44	
Agri-silvi-horticulture	1,60,987	91,706	2.32	Kaushik <i>et al.</i> (2002)
<i>Prosopis cineraria</i> -Cowpea-Toria	19,370	13,579	3.34	
Pearl millet-Toria	15,550	9,365	2.51	
Bamboo + Sudan grass	1,50,205	1,22,405	4.40	Puran <i>et al.</i> (2018)
Bamboo + Guinea grass	90,458	65,858	2.60	
Cashew + Black gram	43,416	10,050	1.30	Dalvi <i>et al.</i> (2020)
Cashew + Niger	36,792	6,156	1.20	
Poplar + Wheat			2.87	Singh and Mavi (2016)
Eucalyptus + <i>S. aculeata</i> + Barley (8-year rotation)	12,56,249	6,65,676	1.57	Dhillon <i>et al.</i> (2018)

Source: Ram *et al.* (2023)

Agroforestry systems for boosting farm income

Agroforestry allows farmers to diversify their income sources by incorporating multiple components into their production systems. Trees in agroforestry systems provide valuable products such as fruit, fuelwood, timber, fodder, and non-timber forest products (NTFPs). This diversification reduces farmers' dependency on a single crop and provides additional revenue streams throughout the year, reducing income risks associated with market fluctuations or crop failures due to climate change. The financial analysis of the different agroforestry systems in India shows that agroforestry gives better economic returns (Table 2).

Role of integrating trees in the farming system in addressing climate vulnerable challenges

Agroforestry, the strategic integration of trees into agricultural landscapes, provides a sustainable solution to mitigate the challenges posed by climate vulnerability in farming systems. It contributes significantly to resilience, adaptability, and productivity in the face of climate change.

Carbon sequestration and climate mitigation: Trees integrated into farming systems play a crucial role as carbon sinks, capturing atmospheric carbon dioxide and mitigating greenhouse gas emissions. In addition, by lowering the demand of fuels and fertilizer, agroforestry can lower the emissions of greenhouse gases like nitrous oxide. Additionally, methane emissions—a significant contributor to greenhouse gas emissions—may be

decreased with silvipasture. By employing a grazing approach that involves moving cattle in a rotational stocking system, silvipasture management can lower methane emissions. Research indicates that agroforestry systems have the potential to sequester between 0.25 and 19.14 tons of carbon per hectare annually, depending on various factors. Key determinants of the carbon sequestration potential in agroforestry systems include the tree species used, planting density, rotation period, and the prevailing agroclimatic conditions. Additionally, agroforestry contributes significantly to soil carbon sequestration, with rates ranging from 0.003 to 3.98 tons of carbon per hectare per year.

Microclimate regulation: Trees improve microclimatic conditions by reducing wind speed, moderating temperature fluctuations, and providing shade, which protects crops and livestock from extreme weather events such as heat waves, cold waves, rainfall variability, hailstorms, erosion risks, and drought. Boundary plantation is considered to protect crops from

lodging due to high wind velocity and natural enemies like insects and pests.

Reduced dependence on external inputs: By integrating nitrogen-fixing trees and organic matter, agroforestry reduces the need for chemical fertilizers and pesticides, promoting eco-friendly farming practices. It has been estimated by Ram *et al.* (2020) that agroforestry tree provides an average of 18 kg leaf litter/tree/year to the soil and also fixes nitrogen in the range of 13-500 kg N/ha/year.

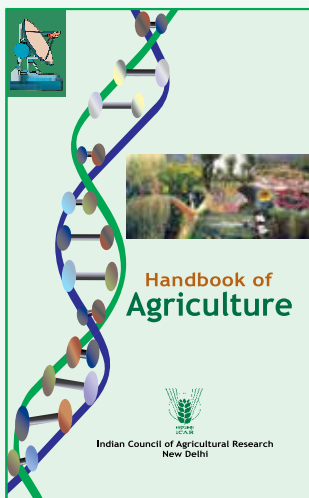
SUMMARY

Climate change poses significant threats to agricultural systems worldwide, compounded by challenges such as resource scarcity, biodiversity loss, soil degradation, and the spread of invasive species. Current farming systems are insufficient to meet the demands of a growing global population in the coming decades. To address these pressing issues, the promotion of novel agroforestry-based integrated farming systems

(IFS) on a larger scale is imperative. These systems offer multifaceted benefits, including mitigating biotic and abiotic stresses, enhancing soil fertility, and optimizing resource utilization. By integrating agroforestry practices, we can create sustainable and resilient agricultural pathways that address modern challenges while fostering ecological and economic stability. The adoption of agroforestry not only strengthens soil systems against climate-induced disruptions in biochemical cycles and nutrient balances but also supports efficient resource management. Technological innovations, precision farming, and sustainable practices further enhance agricultural productivity and resilience to climate challenges. Moving forward, focused research on the adoption and optimization of agroforestry-based farming system will be essential for ensuring sustainability and food security in agriculture.

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The Handbook of Agriculture is one of the most popular publication of the ICAR with a wider readership. The present edition presents science-led developments in Indian agriculture, the ongoing research efforts at the national level and with some ideas on the shape of future agriculture. While information in some chapters such as Soil and water, Land utilization, field and forage crops has been updated with latest developments, many new topics such as the Environment, agrobiodiversity, Resource conservation technologies, IPM, Pesticides residues, Seed production technologies, Energy in agriculture, informatics, Biotechnology, Intellectual Property Rights, Agricultural marketing and trading and Indigenous Technical Knowledge have been included in the present edition. For those who take intelligent interest in agriculture – and their number is increasing fast – the present edition would serve as a useful book.

TECHNICAL SPECIFICATIONS

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