Technical Bulletin
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ICAR Network Project on
Harvesting, Processing and Value Addition of Natural Resins and Gums

ICAR-Central Agroforestry Research Institute
Near Pahuj Dam, Gwalior Road, Jhansi 284003, Uttar Pradesh, India

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Citation

Rajendra Prasad, A.K. Handa, Ramesh Singh, Badre Alam, Ashok Shukla, Prashant Singh, V.D. Tripathi and A. Arunachalam (2021). Economic analysis of gum arabic (*Acacia senegal* (L.) Willd.) based agroforestry model for smallholder farms. Technical Bulletin CAFRI/2021/01, ICAR-Central Agroforestry Research Institute, Jhansi 284003, Uttar Pradesh, India; 34 p.

Technical Bulletin No.: CAFRI/2021/01

Year of Publication: 2021

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Photography:

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Published by:
Director, ICAR-Central Agroforestry Research Institute,
Jhansi 284003, Uttar Pradesh, India

Printed at :
Classic Enterprises, Jhansi 284003, Uttar Pradesh, India
7007122381, 9415113108

Dedication

Late Dr. A. Venkatesh

Dedicated to Dr. A. Venkatesh, Ex-Principal Scientist (Agroforestry) who initiated research to develop gums and resin-yielding tree based agroforestry models under ICAR Network Project on Harvesting, Processing and Value Addition of Natural Resins and Gums in 2009. Most of the scientific data used in this bulletin for financial analysis have been generated from the agroforestry models established by him. Dr. Venkatesh passed away in 2014 at young age of 42 years. He will always be remembered for his academic excellence and farmer-friendly research.

Foreword

Indian agriculture is confronted with key issues of sustainable increase in food grain production and attaining resilience against climate change. Further, by 2050 the Indian population is expected to rise to 1.7 billion requiring about 385 million tons of food grain. Addressing food security and responding to the challenges of climate change are two goals that need to be achieved simultaneously. Adoption of agroforestry land-use on large scale has been advocated as a potential strategy to achieve these twin objectives. However, despite huge potential and benefits from agroforestry, level of adoption of agroforestry technologies by farmers has lagged behind in the whole world. Out of many constraints, the most important reason for non-adoption of agroforestry by smallholders is its long juvenile phase during which resource poor small and marginal farmers do not get any return. To motivate smallholders for adopting agroforestry on their farm land, a need was felt to develop multiple component based, agroforestry models that add value to agroforesrty land-use and also reduce payback period to the minimum. Integration of natural resins- and gum-yielding trees along with some fruit components in agroforestry land-use provide an opportunity to bridge this gap and also help in increasing production base of resins and gums.

The ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi; one of the co-ordinating centres in the ICAR sponsored Network Project "Harvesting, Processing and Value Addition of Natural Resins and Gums" headquartered at ICAR-Indian Institute of Natural Resins and Gums, Ranchi; has been mandated to develop suitable agroforestry models for semi-arid region of Bundelkhand, Central India with focus on development of agroforestry models based on gum arabic (*Acacia senegal*) and *Acacia nilotica.* The institute has developed several models on research farm as well as on farmers' field. The agroforestry model based on gum arabic is getting popularity among farmers of Bundelkhand and hence, the publication **"Economic analysis of gum arabic (*Acacia senegal* (L.) Willd.) based agroforestry model for smallholder farms"** is a timely initiative taken by the institute.

I congratulate the team of Project Investigators for worthy publication of this bulletin. I hope that this scientific publication will be very useful for agroforestry researchers, extension workers, foresters and other stakeholders in diffusing gum-yielding tree based agroforestry among farmers, particularly smallholders of arid and semi-arid regions.

(K.K. Sharma)
Director, ICAR-Indian Institute of Natural Resins and Gums
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Date: March 16, 2021

Preface

Research initiative to develop agroforestry models based on resins- and gum-yielding trees under ICAR sponsored Network Project "Harvesting, Processing and Value Addition of Natural Resins and Gums (HPVANRG)" was started at ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi in the year 2008 with emphasis on gum arabic (*Acacia senegal*) and *Acacia nilotica*. Since then, the institute has established several agroforestry models on research farm as well on farmers' field and generated systematic scientific data. The structural components of gum arabic based agri-horti-silviculture model were designed for smallholder farm to reduce long gestation period, as it is an important bottleneck in disseminating agroforestry among farmers, particularly smallholders. The detailed economic analysis that clearly elaborates rate of return per rupee invested in agroforestry system is pre-requisite for its successful dissemination and adoption by the farmers. Hence, technical bulletin **"Economic analysis of gum arabic (*Acacia senegal* (L.) Willd.) based agroforestry model for smallholder farms"** is brought out to showcase the potential of multiple components including gum-yielding tree based agroforestry system for investment in agroforestry along with economic efficiency of input resources.

The scientific contents embodied in this bulletin are based on systematic research data generated during last ten years at ICAR-CAFRI, Jhansi. The whole text has been divided in six chapters. After introduction in Chapter 1, second Chapter deals with the important natural resins and gums. Chapter 3 highlights botanical description of gum arabic tree and its importance. Chapter 4 deals with integration of natural resins- and gum-yielding trees in agroforestry. The economic analysis of gum arabic based agri-horti-silviculture model is dealt in Chapter 5. At the last, summary and recommendations of benefit-cost analysis have been given in Chapter 6.

The project investigators and authors express their gratitude to Indian Council of Agricultural Research (ICAR), New Delhi for funding the research in the form of Network Project "HPVANRG". The authors thank Dr. T. Mohapatra, Secretary, DARE and DG, ICAR, Dr. K. Alagusundaram, DDG (Agril. Engg.), Dr. S.K. Chaudhari, DDG (NRM), Dr. S. Bhaskar, ADG (AAF&CC), Dr. Kanchan K. Singh, ADG (Engg.), Dr. S. Jha, ADG (Process Engg.), Dr. K.K. Sharma, Director, ICAR-Indian Institute of Natural Resins and Gums (IINRG), Ranchi and Dr. Niranjan Prasad, Project Coordinator of HPVANRG headquartered at ICAR-IINRG, Ranchi for their constant support, encouragement and constructive suggestions. Authors also thank Ex-Directors of the institute, namely Dr. S.K. Dhyani, Dr. O.P. Chaturvedi, Dr. Anil Kumar and Dr. R.K.

Tewari for their motivation, encouragement and guidance in execution of the research work. This publication would not have been made possible without help of Dr. Vikas Kumar, Scientist (Agricultural Economics), ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi in carrying out calculations of benefit-cost analysis. The authors express their thankfulness to him. The authors are highly indebted to the farmers who planted agroforestry models on their farms and given valuable feedback for research. Also, the cooperation and generous help extended by all colleagues is thankfully acknowledged.

It is hoped that this bulletin, embodying financial accounts of agroforestry model suitable for smallholders, will help agroforestry researchers, foresters, extension workers and other stakeholders in scaling up agroforestry on smallholder farms.

Place: Jhansi **Authors**
Date: March 17, 2021

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CHAPTER 1 Introduction

Agroforestry is a multifunctional approach of our food system that involves intentional combination of trees and shrubs with crops or livestock. The concept of integrating trees into the agricultural landscape is as old as the practice of cultivating land. The beneficial outcomes of agroforestry include supply of fuel, wood, fodder and food; non timber forest products (natural resins and gums (NRGs)); carbon sequestration, improvement in soil quality, erosion control, improved wildlife habitat, reduced fossil fuel use, and increase in resilience against climate change (Davis *et al*., 2012). Today, the strategy of agroforestry land-use holds great potential to provide economic, ecological and cultural benefits to the society. Despite huge potential and benefits from agroforestry, level of diffusion of agroforestry technologies among various stakeholders has lagged behind in the whole world (Mercer, 2004). In India too, adoption of agroforestry technologies by smallholders has remained similar to global trend (Prasad *et al*., 2018a).

Out of many constraints, the most important reason for non-adoption of agroforestry in India appears to be its long juvenile phase during which resource poor small and marginal farmers do not get any returns and consequently refrain from adopting agroforestry land-use (Prasad *et al*., 2020a). However, high economic efficiency of limited resources manifested by high returns per rupee invested remains main driving force for agroforesty adoption by smallholder farmers. For achieving twin objective of food security and climatic resilience, many agroforestry systems or models are increasingly being recognized as a viable farming system and widely promoted despite the fact that the economics of such agroforestry systems are not well documented. It is often argued that the traditional rules of economic and financial analyses does not hold true to analyze agroforestry systems because of their complexity and site specificity. Thus, the profitability from agroforestry system remains highly dependent on location and site specific characteristics. Different scholars have studied financial and economic profit of various agroforestry systems practiced in India (Sharma and McGregor, 1991; Jain and Singh, 2000; Dwivedi *et al*., 2007; Chavan and Dhillon, 2019). However, role of many alternative agroforestry systems embracing specific produce such as resins and gums that add value to existing agroforestry practices remain undocumented.

The gums and resins trade in India faces declining trend owing to degrading production base due to ruthless tapping and unorganized harvesting approaches. However, the demand for NRGs has continuously been increasing in the world market for last three decades. Integration of NRGs yielding trees in agroforestry land-use may help in increasing production base of gums and resins, and provide a new option of livelihood support to smallholders at the edge of climatic vulnerability. As per Economic Survey of Ministry of Finance (2011), forest produce based industries contribute to 1.2% in India's Gross Domestic Product. In our country, about 1.73 lakh villages are located in and around forests (MoEF, 2006). According to one estimate, about 350-400 million people depend on the forests and earn their livelihood from non timber forest produce (MoEF, 2009) (Plate 1). Almost 70% of the NTFPs are being collected from tribal belt of the country and about 55% of employment in forestry is attributed to this sector alone (Joshi, 2003). In India, the bulk of commercially important gums comes from the forests of Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Odisha, Jharkhand and Bihar. The gum producing areas are the Western Ghats, Eastern Ghats and surrounding areas. In India, around 30 plant species yield important resins and gums. Among various gum-yielding plant species, *Sterculia urens* Roxb. (*gum karaya*), *Anogeissus latifolia* Roxb. (*gum dhawara*), *Acacia nilotica* (L.) *(gum acacia)*, *Acacia senegal* L. (Willd.) *(gum-arabic)* and *Tamarindus indica* L. (*tamarind gum*) are important. *Butea monosperma* (Lam.) Taub. is also one of the most important plant species which yields a valuable gum called *kamarkas*. Among resin-yielding plant species, the important ones are *Pinus roxburghii* Sarg. (*pine resin*), *Shorea robusta* Gaertn. (*sal resin*), *Boswellia serrata* Roxb. (*salai*), *Canarium strictum* Roxb. (*black dammar*) and *Commiphora wightii* (Am.) Bhandari (*guggul*). India holds monopoly in international trade over some of the NRGs such as lac, *gum karaya* and *guar gum*.

Plate 1. Saharia tribe women employed in value addition processes for natural gum.

The farmers are always inclined to adopt a land-use system or new agricultural technologies that maximize their profit. Adoption of agroforestry models by small farmers can be enhanced if the agroforestry models are supported with the detailed economic analysis that clearly elaborates rate of return per rupee invested in agroforestry systems (Prasad *et al.*, 2020a). The agroforestry systems based on gum arabic are getting popularity among farmers of semi-arid region of Bundelkhand and therefore, it is essentially required to carry out benefit-cost analysis of such agroforestry models. The main objective of this compilation is to present benefit-cost analysis of a small holding gum arabic based agri-horti-silviculture model systematically so that smallholders get sufficient factual data and moral support for taking decision in favour of adopting agroforestry on their farms.

CHAPTER 2 Important Natural Resins and Gums

The NRGs are most important non timber forest products (NTFPs) widely traded in national and international markets. Based on their chemical composition, the NTFPs may be classified in three categories, namely natural resins, natural gums and gum-resins. Natural resins are solid or semi-solid materials, usually a complex mixture of organic compounds called terpenoides which are insoluble in water but soluble in certain organic solvents. Resins are secretion of several plants, particularly coniferous trees. These are used in production of varnishes, adhesives and food glazing agents, and also as raw material for synthesis of incense and perfume. This group of natural resins include lac secreted by an insect *Kerria lacca* Kerr. and plant originated products like rosin, copal and *dammar*. Solidified resin from which the volatile terpene components have been removed by distillation is known as rosin. Natural gums are polysaccharides of natural origin capable of causing a high viscosity in the solution. Most often these gums are found as exudates from woody elements of plants or in seed coatings. In food industry, these are used as thickening, gelling and emulsifying agents and stabilizers. These are also used as adhesives, binding agents, crystal inhibitors, clarifying agents, encapsulating agents, flocculating agents, foam stabilizers, swelling agents etc. Natural gums can be classified according to their origin. Firstly, tree exudates e.g. *gum-arabic, gum ghatti, gum karaya, guar gum, locust bean gum, chicle gum, dammar, mastic gum, psyllium gum* and *spruce gum*; secondly, originated from seaweeds e.g. agar and carrageenan; and thirdly, produced by bacterial fermentation e.g. gellan gum and xanthum gum. These can also be classified as uncharged or ionic polymers (polyelectrolyte). Gum-resins are the natural mixtures of gums and resins in variable proportions; therefore, possess properties of both the groups. They contain traces of essential oils and are partly soluble in water. They have a penetrating and characteristic odour and taste, and obtained from the plants. Olibanum/salai gum, guggul , myrrh, asafoetida, etc. are the major gum-resins of importance.

According to International Trade Centre statistics, the world trade aggregation of lac, natural gums, resins, gum-resins and balsams during 2015 was about 1220.16 million US$. Out of this, the world export was about 436.70 million US$. Major suppliers of NRGs contributing about 92% share in the international market are France (31.2%), India (15.6%), USA (8.3%), Germany (7.1%), UK (6.1%), Thailand (5.9%), Brazil (4.5%), Singapore (2.7%), Ethiopia (2.6%), Greece (2.5%), Italy (2.2%), Netherlands (1.4%), China (1.1%) and Malaysia (1.0%). Rests of the NRGs (7.6%) are supplied from 83 countries across the world. Similarly, the world import aggregation of lac, natural gums, resins, gum-resins and balsams during 2015 was about 783.45 million US$. Major importers of NRGs contributing about 80% share in the international market are India (17.0%), France (13.6%), USA (11.2%), Germany (5.2%), China (4.7%), Italy (3.9%), Netherlands (3.4%), UK (3.3%), Portugal (2.8%), Russian Federation (2.6%), Singapore (2.5%), Saudi Arabia (2.4%), Spain (2.3%), Brazil (2.1%), Ireland (2.0%), Japan (1.6%), Switzerland (1.4%) and Thailand (1.3%). Rest of the demand of NRGs (16.6%) aroused from the 115 countries across the world (Yogi *et al*., 2018).

2.1 Natural resins

***Pine resin*:** Rosin is a natural product of pine resin. Rosin and its derivatives have been used as paper-sizing agents, emulsifiers, surface coatings, chewing-gums, tackifiers in adhesives, insulating materials and additives for printing inks. It has also been evaluated for application in pharmaceutical as microencapsulating materials (Lee and Hong, 2002; Tang, 2003). Pine resins are secretion of plants, particularly coniferous trees. Extensive chir pine forests are found in the Himalayas, between an elevation of 1000 to 1900 m. Chir pine yields commercially important oleo-resin which forms the raw material for rosin and turpentine oil industry in India. Chir pine is widely tapped for resin on commercial basis, particularly in the hills of Himachal Pradesh, Uttarakhand, Jammu & Kashmir and north-eastern states. The northern hill states annually produce around 8000 to 9000 tons of raw rosin extracted from pine trees.

***Copal*:** Copals are derived from species of *Bursera*, *Protium* (Burseraceae) and *Hymenaea*. The adhesive property of copal makes it a potential coating material. In India, more than 99% of the copal was supplied from Indonesia (96.83%) and Philippines (3.06%) during 2015-16. A very little portion of the total imported quantity was exported to Thailand (90.21%) and Canada (9.79%) during 2014-15.

***Dammar batu*:** Dammar is tapped from the *S. robusta*, although some is still collected from the ground in fossilized form. Annual production of dammar batu in India is about 80-100 tons. It is used as painting and incense material. During 2015-16, more than 95% of this resin in India was supplied from Indonesia (58.60%) and Thailand (38.77%). A very little portion of the total imported quantity was exported to Japan (58.05%), Jordan (33.74%), Canada (7.29%) and Vietnam (0.46%).

2.2 Natural gums

The gum tapping is mainly done in the schedule areas where tribal population exist. The collection charges to the collectors at collection centres are paid by the purchaser at the rate fixed by the Government. In India, mainly *karaya gum*, *dhawara gum*, *prosopis gum* (*Prospois juliflora* (Sw.) DC.), *khair gum* (*Acacia catechu* (L.f.) Brandis), *gum acacia*, *jhingan gum* (*Lannea coromandelica* (Houtt.) Merr.), *kamarkas*, *piyar gum* and *guggul* are produced. Exudate gums possess a unique combination of functionalities and properties that can never be matched by any other alternative synthetic polymers, which makes their complete substitution impossible. Importantly, these biopolymers are eco-friendly as they are biodegradable. About 81% of gum production in the country is contributed by Maharashtra (26.9%), Madhya Pradesh (18.8%), Jharkhand (13.5%), Telangana (12.8%) and Chhattisgarh (8.9%). Rest of the 19% comes from Gujarat (4.4%), Andhra Pradesh (4.2%) and other minor gum producing states (10.5%).

Gum karaya: *Gum karaya* is the dry exudate of *S. urens* and *Sterculia villosa* Roxb. ex Sm. It is also collected from *Sterculia urceolata* Sm. and *Sterculia foetida* L. in Indonesia; *Sterculia setigera* Del. in Africa; and *Sterculia caudata* Heward ex Benth. in Australia (Gautami and Bhat, 1992). *Gum karaya* is one of the least soluble gums used for many industries *viz*., pharmaceutical, food, paper, textiles, cosmetic industry, superior grades in ice-creams, inks, rubber, linoleum, oil clothes, paper coatings, polishes and lower grades in varnishes. In India, its overall production has decreased from 6,838 (1975–76) to 100.35 tons (2015-16). During this period, the price increased from Rs. 7.4 to 110 kg^{-1}. The states of Chhattisgarh and Jharkhand are the main producer.

***Dhawara gum* or *gum ghatti*:** *Dhawara gum* is the dry exudate of *A. latifolia*. It has a glassy fracture and occurs in rounded tears which are normally less than 1 cm in diameter. It often occurs in larger vermiform masses. *Dhawara gum* is used as an emulsifier and stabilizer in beverages and butter containing table syrups; flavour fixative for specific applications; as a binder in long-fibered light weight papers; as an emulsifier of petroleum and non petroleum waxes to form liquid and wax paste emulsions; to prepare uniform and discrete prills of cross-linked polystyrene; as drilling mud conditioner and acidizing oil wells and also used in powdered explosives to improve resistance to water damage. *Dhawara gum* is produced in the states of Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh, Maharashtra and Andhra Pradesh. In India, total production of *dhawara gum* increased from 2.7 tons (2011-12) to 194 tons (2015-16).

Gum-arabic: *Gum-arabic* is a natural gum made of the hardened sap of *A. senegal*. Producers harvest the gum commercially from wild trees, mostly in Sudan (80%). The uses of *gum-arabic* are linked to its two main characteristics i.e. its high solubility in water and low viscosity. This gives *gum-arabic* eminent qualities as an emulsifier, stabilizer, thickener or adhesive of a non-toxic nature. Pharmaceutical drugs and cosmetics also use it as a binder, emulsifying agent and a suspending or viscosity increasing agent. Production of *gum-arabic* is excellent on poor soils and higher in stressed trees. Gum exudes from the duct of the inner bark and is tapped in the hot season (May-June) when trees are under stress. Annual production of *gum-arabic* in India is about 5-10 tons. Production of *gum-arabic* is concentrated within a 520000 km^2 radius of Central Sudan, commonly known as the gum belt. The three main producing countries are Sudan, Nigeria, Cameroon and Chad which cover about 82% of the global export market of the *gum-arabic*. There is high demand of *gum-arabic* in India. About 4000 tons of *gum-arabic* exported to Nepal (53.02%), Bangladesh (37.58%) and China (2.61%) during 2015-16. The international market for *gum-arabic* is subject to different trends and fluctuations.

2.3 Natural gum-resins

Asafoetida, salai gum and myrrh are the major gum-resins. About 1100 tons of the gum-resins has been exported from the country that earned Rs. 657 million foreign exchange during 2015-16.

Asafoetida (Hing): Asafoetida (*Ferula anthrax* Boiss. and *F. foetida* Regel.) is a popular spice used in daily food by the Indians. It was found to contain mainly ferulic acid, umbellic acid and ketonic substance known as umbelliferone. Powder of asafoetida is used as carminative and also used in fainting, flatulent colic and chronic bronchitis as well as to treat asthma in adults (Kokate *et al.,* 2002). New pharmacological investigations indicate possible anti-inflammatory, anti-diabetic and anti-bacterial effects (Bhatnager *et al.,* 2015). In India, asafoetida is supplied from Afghanistan (90.44%) and Uzbekistan (7.32%). On other hand, UAE (27.25%), USA (14.78%), Saudi Arab (7.33%) and Singapore (7.01%) are the major export destination of asafoetida.

Salai gum: *Salai gum* (*Frankincense*), also known as Olibanum, is an aromatic oleogum-resin obtained as pale yellow to red tears from the bark of trees belonging to the genera *Boswellia* of the Burseraceae family thriving in arid regions of Africa and southern Arabia. There are 43 different species reported in India, Arabian Peninsula and North Africa. It is an important component in cosmetic industry and also marketed widely as a food supplement (Khan *et al*., 2014). It's smoke is a powerful insect deterrent and thus serves as a prophylactic to prevent the bites of the malaria carrying mosquitoes.

B. serrata is a deciduous middle sized tree, which is mostly concentrated in tropical areas; parts of Asia and Africa. In India, it occurs in dry hilly forests of Rajasthan, Madhya Pradesh, Gujarat, Bihar, Assam, Odisha as well as central peninsular regions of Andhra Pradesh, Assam etc. This gum is tapped from the incision made on the trunk of the tree which is then stored in specially made bamboo basket and converted into different grades of materials according to flavour, color, shape and size. Harvesting of frankincense is a time consuming process that begins in December, reaching a peak from March to May (Marshall, 2003). The trees start producing resin when they are about 8 to 10 years old. In India, olibanum is supplied from UAE (57.53%), Somalia 23.43%), Yemen Republic (12.43%) and Ethiopia (5.53%). Trinidad (26.66%), Germany (12.69%), Mauritius (7.63%), Morocco (7.42%), Mexico (7.35%) and USA (6.61%) are the major export destinations.

***Myrrh*:** Myrrh comes from a small, thorny tree *Commiphora myrrha* (Nees) Engl., cultivated since ancient times in the Arabian Peninsula. The growers make a small cut in the bark, from where the resin would leak out. It is then collected and stored for about three months until it hardens into fragrant globules. Myrrh is used raw or crushed and mixed with oil to make perfume. Myrrh oil, which is steam distilled directly from the myrrh resin, has an aroma that is woody, earthy and a bit balsamic. Also, myrrh is occasionally used as a flavoring agent. Somalia and Ethiopia are the largest producers of the substance. In India, myrrh is supplied from UAE (61.48%), Somalia (24.07%) and Kenya (6.96%). Turkey (47.21%), Iraq (47.21%) and UK (3.62%) are the major export destinations.

CHAPTER 3 Botanical Description and Importance of Gum Arabic Tree

Gum arabic scientifically known as *Acacia senegal* or *Senegalia senegal* (L.) Britton, belonging to family Mimosaceae, is an important gum-yielding tree species. Its known sub species/varieties are *kerensis, rostrata* and *leiorhachis.* The vernacular names in Hindi include kumat, kumta and humtha. It is a deciduous medium sized tree growing from 3 to 12 m in height. From main trunk, ramification occurs at 1-1.5 m height, much branching with many upright twigs with wider spreading (Plate 2). Branches fork repeatedly and in mature trees, commonly form a rounded, flat-topped crown. The trunk may vary in diameter up to about 30 cm. The bark is grayish-white in color, although in old trees growing in the open, it may be dark, scaly and thin, showing the bright green cambium layer just below the surface if scratched with a nail. The slash is mottled red. Powerful hooked thorns, 3-5 mm long, with enlarged bases appear at the nodes of the branches, usually in triplets. They are sharp, with some pointing forwards and others backwards. Leaves bipinnate, 3-8 pinnae (glands between uppermost and lowermost pinnae); rachis up to 2.5 cm long; pinnacles are in pairs of 8-15, green; 2 stipular spines strongly recurved with a 3rd pseudo-stipular between them. Flowers yellowish-white and fragrant, in cylindrical, axillary pedunculate spikes, 5-10 cm long; calyx of each flower has 5 deep lobes, 5 petals and a mass of short stamens; pistil inconspicuous. The pods are straight, thin, flat, shortly stipitate and oblong (7.5 × 2 cm), green and pubescent when young, maturing to shiny bronze, often with dark patches and bearing prominent veins; seeds 3-6, smooth, flat, rather small, shiny, dark brown. Varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as the presence or absence of hair on the axis of the flower spike, color of the axis, shape of pod tips, number of pinnae pairs, occurrence of a distinct trunk and shape of the crown. Flowering from January to March, and Fruiting from January to April. Considerable variability exists in flowering and fruiting.

It is distributed in tropical Africa from Mozambique, Zambia to Somalia, Sudan, Ethiopia, Kenya, Tanzania and Nigeria, and in South Asia, in India and Pakistan (Raddad and Lukkanen, 2007). It thrives well in arid and semi-arid regions with a low rainfall of 100-250 mm (Ballal, 1991). It can tolerate prolonged dry spells (10-11 months), with maximum temperature reaching 50^{0}C and strong winds (Fadl, 2013). It occurs mostly on rocky, gravelly and skeletal soils, and widely distributed as interspersed species in most of the rangelands and grasslands in the arid and semi-arid regions of the India (Prasad *et al.*, 2015).

Plate 2. Full grown tree of gum arabic (*Acacia senegal*).

Plate 3. Naturally exuded gum tears of gum arabic (*Acacia senegal*).

A. senegal yields a high quality (Table 1) valuable edible gum called *gum-arabic* (Plate 3), which is an important commercial produce and contributes significantly to economy of African countries (Ballal *et al*., 2005; Fadl and Sheikh, 2010). World's 90% *gum-arabic* is produced from *A. senegal*. Kordofan, a province of central Sudan, produces approximately 90% *gum-arabic*. In India, its production is meager and contributes negligibly in world's total production. In our country, its production is insufficient even for domestic consumption; hence, being imported from Sudan and Nigeria. In Sudan, younger tree yields 188 to 2856 g (average 0.9 kg) and older tree yields 379 to 6754 g (average 2.0 kg) *gum-arabic,* annually. In our country, its productivity is relatively less which varies from 175 to 550 g tree^{-1} year^{-1} (Prasad *et al*., 2015). Besides, the seeds of *A. senegal* are also edible and used as an important constituent of famous delicious vegetable dish called *panchkuta* and pickles in Rajsthan. Production of seeds varies from 300 g to 1.2 kg tree^{-1} depending on age of the tree and monsoon rain. *A. senegal* also provides good fodder and/or browse material in lean period. Its leaves and pods are browsed by sheep, goats and camel. The wood of *A. senegal* with calorific value of 3000 Kcal kg^{-1} is suitable for coal making and fuel wood. Being a leguminous tree, *A. senegal* improves soil fertility (Prasad *et al*., 2019b) and also sequesters atmospheric carbon. Studies at ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi have revealed that at age of 7 years, *A. senegal* sequestered 5.56 tons carbon ha^{-1} at sequestration rate of 0.79 tons ha^{-1} year^{-1} (Prasad *et al*., 2019).

In India, natural as well as planted stands of *A. senegal* are present in desert and arid regions of Rajasthan, Gujarat, Haryana and Punjab (Raj *et al*., 2015). Bundelkhand region of Central India can host large scale plantation of *A. senegal*, as the region is situated in semi-arid tropics (Singh *et al*., 2017). Bundelkhand region is prone to frequent drought and climatic conditions are suitable for production of *gum-arabic* which may provide livelihood security to marginal farmers. As per an estimate, a farmer who plants 100 trees ha^{-1} at spacing of 10 m × 10 m will harvest about 25 kg *gum-arabic* assuming average yield of 250 g tree^{-1}. It may generate revenue of Rs. 12,500 ha^{-1} year^{-1}, if gum is sold @ Rs. 500 kg^{-1} (Prasad *et al*., 2018b). Integration of *A. senegal* in agroforestry system can be a profitable option. It has shown its potential as a promising tree species for agroforestry systems in African countries (Fadl and Gebauer, 2004 and 2005; Fadl, 2013). In India, it has given good results when planted with moong bean, cluster bean and pearl millet in arid regions of Rajasthan (Tewari and Singh, 2006).

Table 1. Physical, chemical and biological quality characteristics of *gum-arabic* obtained from *Acacia senegal* (Mertia *et al.*, 2009; Uikey, 2013).

Quality parameters	International specifications of *gum-arabic* as per *IP, JECFA, USP and BP	Values of *gum-arabic* (*A. senegal*)	Remarks
Moisture content (%)	<15.0	3.5	15% is maximum limit for food and pharmaceutical use
Ash content (%)	<4.0	3.0-3.9	For food and pharmaceutical quality, total ash should not exceed 4%
pH	-	4.3-4.4	Acidic pH causes more irritation in gastrointestinal tract
Nitrogen content (%)	-	0.27-0.44	Indicates emulsifying behaviour. High values are good
Protein (%)	-	1.8-3.0	-
Water insoluble matter (mg 5 g^{-1})	-	12.0	Should not exceed 50 mg
Loss on drying (%)	-	3.03	Should not exceed 15 per cent
Acid insoluble ash (%)	-	0.19	Should not exceed 1.0 per cent
Viscosity at 40°C (CPS)	-	18	-
Viscosity at 100°C (CPS)	-	12	-
Heavy metals (ppm)	-	<20.0	-
Yeast and moulds g^{-1}	-	<100	-
E. coli (12.4 g^{-1})	-	Negative	-
Salmonella (25 g^{-1})	-	Negative	-
Staphylococcus aureus (10 g^{-1})	-	Negative	-

*IP = International Pharmacopoeia; JECFA= Joint Expert Committee for Food Additive; USP = United State Pharmacopoeia; BP = British Pharmacopoeia

CHAPTER 4 Integration of Natural Resins- and Gum-yielding Trees in Agroforestry

Tree products *viz*., fodder, wood, fuel, fruits, nuts, resins, gums, extractives and medicines make agroforestry the best land-use system in the era of changing climate. This is the reason why agroforestry has been widely promoted in tropical countries. In India, the estimated area under agroforestry is about 25.3 million ha (Dhyani *et al*., 2013) which is likely to increase substantially in the near future. There are many gum-yielding tree species which can be planted as woody components along with crops in agroforestry. The associated crops and trees can vary from region to region and such agroforestry models will be highly beneficial in providing livelihood security to the resource poor farmers.

4.1 Natural resins- and gum-yielding trees suitable for agroforestry in different climatic regions

The agroforestry models can be developed by planting selected tree species for the given agro-climatic condition. Trees can be planted on boundary of the field or as rows inside the field. The distance between row to row and tree to tree in a row depends on growth behaviour of tree species and associated crops. Generally, row to row distance should be kept wide so that agricultural operations can be performed without any hindrance. To reduce harmful effects of trees on associated crops, tree pruning must be conducted. The associated crops should be selected on the basis of identified tree species and its growth behaviour so that both components (woody and annual crop) offer minimum competition to each other. For development of gum and resin based agroforestry models, selection of tree species which produce gums and resins is the first requisite. The tree species identified for different climatic regions are given below:

Arid and semi-arid: *A. nilotica, A. catechu, A. senegal, A. latifolia, Bauhinia retusa* Poir*., Bombax ceiba* L., *B. serrata, B. monosperma, Commiphora mukul* (Hook. Ex Stocks) Engl.*, S. robusta* and *S. urens.*

Sub humid: *A. catechu, B. ceiba, C. strictum, Dipterocarpus turbinatus* Gaertn., *Garcinia morella* (Gaertn.) Desr., *Hopea odorata* Roxb. and *S. robusta.*

Humid tropics: *B. ceiba, C. strictum, Cochlospermum religiosum* (L.) Alston, *D. turbinatus, G. morella, H. odorata, Kingiodendron pinnatum* (DC.) Harms, *L. coromandelica, P. wallichiana, S. urens* and *Vateria indica* L.

Sub-tropical: *A. nilotica, A. catechu, A. senegal, A. latifolia, B. retusa, B. ceiba, B. serrata, B. monosperma, C. religiosum, C. mukul, G. morella, H. odorata, K. pinnatum, L. coromandelica, P. roxburghii* and *S. urens.*

Temperate: *B. monosperma, D. turbinatus, G. morella, K. pinnatum, P. roxburghii* and *V. indica.*

Moist region: *D. turbinatus, K. pinnatum, P. roxburghii, P. wallichiana* and *V. indica.*

4.2 Natural gum-yielding trees based agroforestry models for Bundelkhand

At ICAR-CAFRI, Jhansi, one of the co-ordinating centres in the ICAR Network Project "Harvesting, Processing and Value Addition of Natural Resins and Gums (HPVANRG)", efforts are made to develop suitable agroforestry models based on resins and gum-yielding trees for semi-arid region of Bundelkhand, Central India. The major thrust is being given to develop agroforestry models based on gum-yielding trees, namely *A. senegal*, *A. nilotica* and *Anogeissus pendula* Edgew. Besides, agroforestry models are also disseminated on farmers' field.

Since 2008, efforts are made to establish agroforestry models on research farm of ICAR-CAFRI to generate scientific data on growth and productivity. Five agroforestry models integrating *A. senegal* and *A. nilotica,* representing either agri-silviculture, agri-horti-silviculture or horti-silviculture system of agroforestry, have been established at research farm. The horticulture species planted in different models included, *Citrus limon* (L.) Osbeck. (lemon), *Aegle marmelos* (L.) Correa (bael) and *Carissa carandas* L. (karonda). *A. segenal* and/or *A. nilotica* were planted either on boundary or as row plantation. In rainfed agroforestry model, *A. senegal* and *A. nilotica* have been planted in three spacing *viz*., 10 m × 10 m, 10 m × 5 m and 5 m × 5 m (Plate 4). In rocky hill and degraded rocky foothill, block plantation of *A. senegal* has been done to establish a gum garden (Plate 5). Beside aforesaid agroforestry models, four bio-fence models have also been established at the research farm during 2018 wherein *A. senegal* along with *C. carandas* have been planted in single and double rows on field boundaries. Bio-fence model-1 aimed to optimize distance apart trees consists of single row plantation of *A. senegal* + *C. carandas* alternated in three distances i.e. 1.0, 1.5 and 2.0 m apart on field boundaries. Bio-fence model-2 aimed to assess effectiveness of double row planting consists of *A. senegal* as outer row and *C. carandas* as inner row on field bunds. Distance between two rows was 1.0 m and within the row, plant to plant distance was 2.0 m. The planting of both species in two rows was done in staggered manner. Bio-fence model-3 aimed to assess the effectiveness of double row planting of *A. senegal* at different spacing. This model was planted on three sides of field boundary of a well-established *Emblica officinalis* Gaertn. (aonla) orchard. Plant to plant distance was kept uniform at 1.5 m in both the tree rows, while the distance between two rows varied at all three sides of the field i.e. 1.0, 1.5 and 2.0 m. Planting was done in staggered manner in two rows. The bio-fence model-4 consists of two rows of *A. senegal* (inner and

Plate 4. Growth of six year old *Acacia senegal* and *Acacia nilotica* in rainfed agroforestry model at ICAR-CAFRI, Jhansi.

Plate 5. Growth of five year old *Acacia senegal* in block plantation on degraded rocky foothills at ICAR-CAFRI, Jhansi.

outer) kept at 1.5 m apart wherein plant to plant distance in a row was also 1.5 m. This model was planted along two sides of a well-established *Punica granatum* L. (pomegranate) orchard. Planting was done in staggered manner in two rows. Tree growth and productivity data from all the agroforestry models are being recorded.

For dissemination of gum-yielding tree based agroforestry models, farmers were motivated to adopt tree based land-use systems on their farm in selected villages. Four agroforestry models have been planted on farmers' field integrating *A. senegal* and *A. nilotica* along with horticulture species like *E. officinalis*, *Psidium guajava* L. and *C. carandas* (Plate 6). *A. senegal* and/or *A. nilotica* are planted on field boundaries. Trees in these agroforestry models are monitored for growth and gum exudation.

Plate 6. Boundary plantation of *Acacia senegal* in *Emblica officinalis* based agroforestry model at farmer field.

Observations on comparative growth of *A. senegal* and *A. nilotica* from agroforestry models established on research farm and farmers' fields revealed that survival and growth of gum-yielding trees was more in models developed at ICAR-CAFRI research farm than the models on farmers' field. Out of two gum-yielding tree species, better performance has been shown by *A. nilotica* than *A. senegal* (Figure 1). The main reason of poor survival and growth of planted species on farmers' fields was inadvertent damage by mechanized operation and uncontrolled grazing due to practice of *anna pratha.* In *anna pratha*, the cattle are let loose which openly graze and tremble growing saplings planted on farmers' field. The planted seedlings require to be protected from moving cattle in beginning for two to three years and also from mechanized operations with tractor.

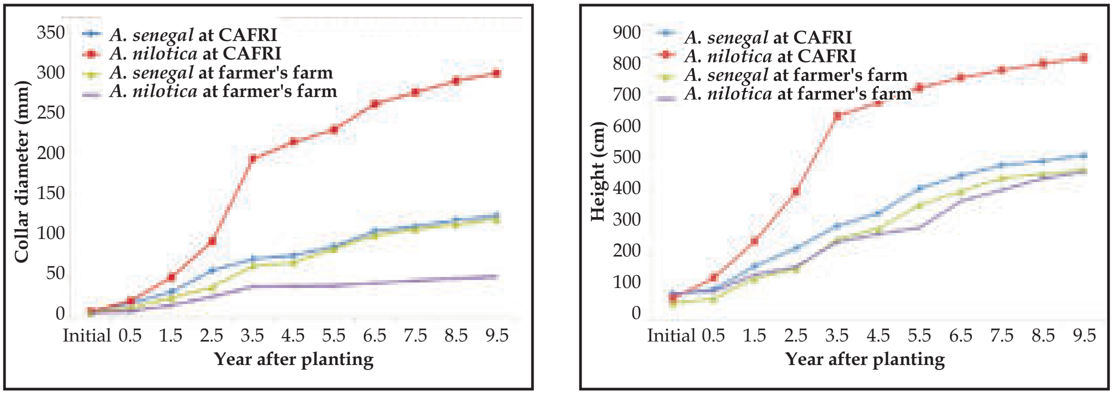

Figure 1. Comparative performance of gum yielding trees (*Acacia senegal* and *Acacia nilotica)* at research farm and farmer's field.

Despite constraint of *anna pratha* in Bundelkhand, the farmers of the region are getting attracted toward *A. senegal* based agroforestry models developed at ICAR-CAFRI, Jhansi (Prasad *et al*., 2018c), and many farmers have planted it on their fields. The Institute is helping farmers and providing seedlings free of cost. During last five years, about 10,000 seedlings of *A. senegal* have been planted in villages Parasai, Chhatpur and Bachouni of district Jhansi (Uttar Pradesh) and villages Shivrampur, Dabar and Garhkundar of district Tikamgarh (Madhya Pradesh) on farmers' field mainly as boundary plantation (Figure 2). Apart from this, approximately 50,000 seedlings of *A. senegal* have been provided to enable "Doubling Farmers' Income (DFI)" for planting in seven districts of Bundelkhnad region of Uttar Pradesh. The farmers preferred this species as it acts as live fence besides yielding valuable *gum-arabic* (Prasad *et al*., 2018c and 2019a).

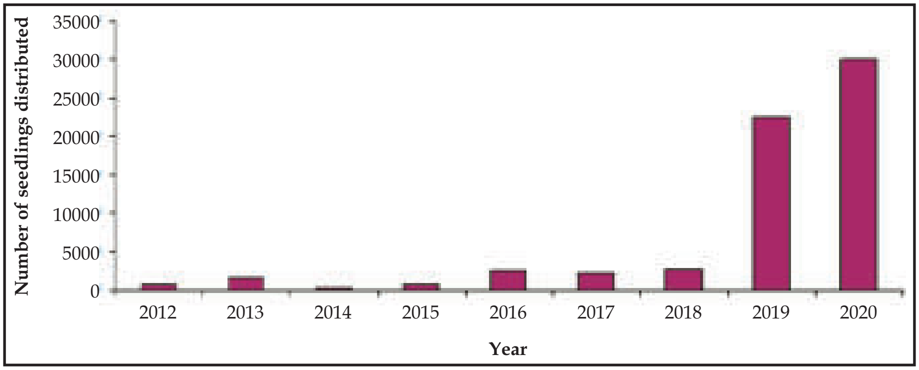

Figure 2. Number of seedlings of *Acacia senegal* planted on farmers' fields.

CHAPTER 5

Economic Analysis of Gum Arabic based Agroforestry Model

5.1 Structural components

There were five structural components including woody and fruit trees, and crops in gum arabic based agri-horti-silviculture model. These components were designed for smallholder farmers (0.5 ha) in such a way that the payback period from investment on agroforestry system is reduced assuming production of fruits from *C. carandas* and/or *C. limon* will start after 3-4 years of planting. Long gestation period of agroforestry system is an important bottleneck in disseminating agroforestry among farmers particularly smallholders. Integration of three horticultural fruits in gum arabic based agroforestry model is likely to reduce the payback period and also increase risk bearing capacity against vulnerability to climate change thus, making this model more climate resilient. Out of five components *viz*., intercrops, *C. carandas*, *A. marmelos*, *C. limon* and gum arabic (*A. senegal*), four are woody perennials and likely to compensate the losses of failed intercrops due to abnormal monsoon rain or any extreme weather events.

5.2 Design

Gum arabic based agri-horti-silviculture model, comprising of gum-yielding (*A. senegal*) and horticulture plant species, namely *C. limon*, *A. marmelos* and *C. carandas* was established at central research farm of the institute during July, 2009 under HPVANRG project. The total area of the field is 72 m (width) and 68 m (length). In the model, 28 plants of *A. senegal*, 28 plants of *A. marmelos* and 24 plants of *C. limon* were planted in rows. Row to row distance of *A. senegal* and *A. marmelos* was 20 m and in a row, plant to plant distance was 10 m. In every row of *A. senegal*, *C. limon* was planted 10 m apart (one lemon plant between two gum arabic). Thus, the model consists of eight rows, wherein first row comprises of *A. senegal* and *C. limon* (var. Kagzi) placed 5 m distance from each other (thus, 13 trees in a row), which is being alternated with *A. marmelos* row, planted at 10 m distance from each other (thus, 7 trees in a row). *C. carandas* was planted at three sides of field bunds (Figure 3). Intercropping commenced from 2009-10 and continued thereafter. The cropping sequence – *Vigna radiata* (green gram)/*Phaseolus mungo* (black gram) – *Lens culinaris* (lentil)/*Brassica campestris* (mustard)/*Triticum aestivum* (wheat) was adopted for summer-winter seasons (Table 2). Monthly distribution of rainfall during 2009-2019 has been given in Table 3. Due to abnormal monsoon rains, the summer crop often failed or performed poorly. The annual growth data of tree components was recorded in the month of January-February every year. The growth data of tree components for the year 2019-

20 is given in Table 4. The growth and yield data of intercrops were also recorded by fixing quadrat (1 m x 1 m) at different distances from the tree line, to assess tree-crop interactions (Prasad *et al*., 2018c). For cultivation of intercrops, standard package of practices was followed. Pruning of tree's crown was generally carried out in the month of October i.e. before taking winter crops and pruned material was taken out to be used as fuel wood, except leaves and fine twigs which were left in the field for decay. The system started yielding fruits (*C. limon* and *C. carandas* during 2012-13, and *A. marmelos* during 2015-16) and *gum-arabic* through natural exudation during 2014-15 (Plate 7 and 8). The fruits of *C. limon* and *C. carandas* were plucked manually and sold locally. The fruits of *A. marmelos* were auctioned.

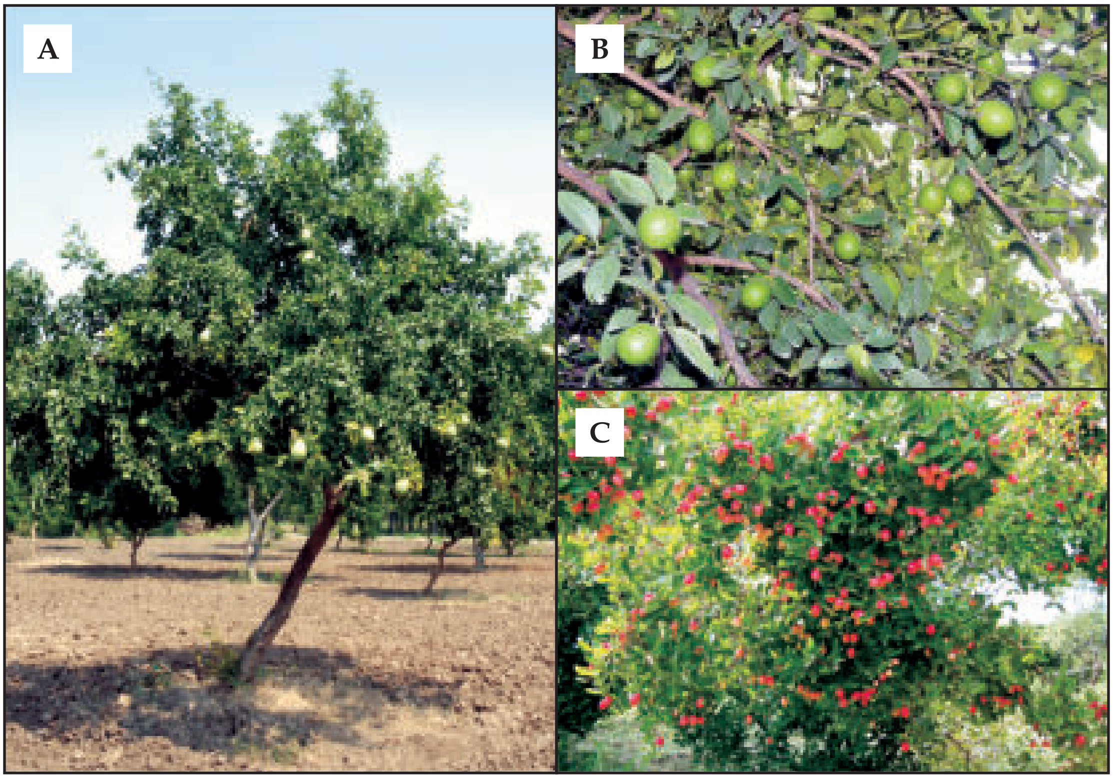

Plate 7. Fruiting on *Aegle marmelos* (A), *Citrus limon* (B) and *Carissa carandas* (C) in agri-horti-silviculture model at research farm of ICAR-CAFRI, Jhansi.

Plate 8. Natural exudation of *gum-arabic* from *Acacia senegal* tree at research farm of ICAR-CAFRI, Jhansi.

Table 2. Cropping sequence adopted in agri-horti-silviculture model at research farm of ICAR-CAFRI, Jhansi.

Year	Intercrops grown	
	Summer	Winter
2009-10	Black gram	Mustard
2010-11	Black gram	Lentil
2011-12	Black gram	Mustard
2012-13	Green gram	Mustard
2013-14	Green gram	Mustard
2014-15	Green gram	Wheat
2015-16	Black gram	Wheat
2016-17	Black gram	Wheat
2017-18	Green gram	Mustard
2018-19	Green gram	Wheat

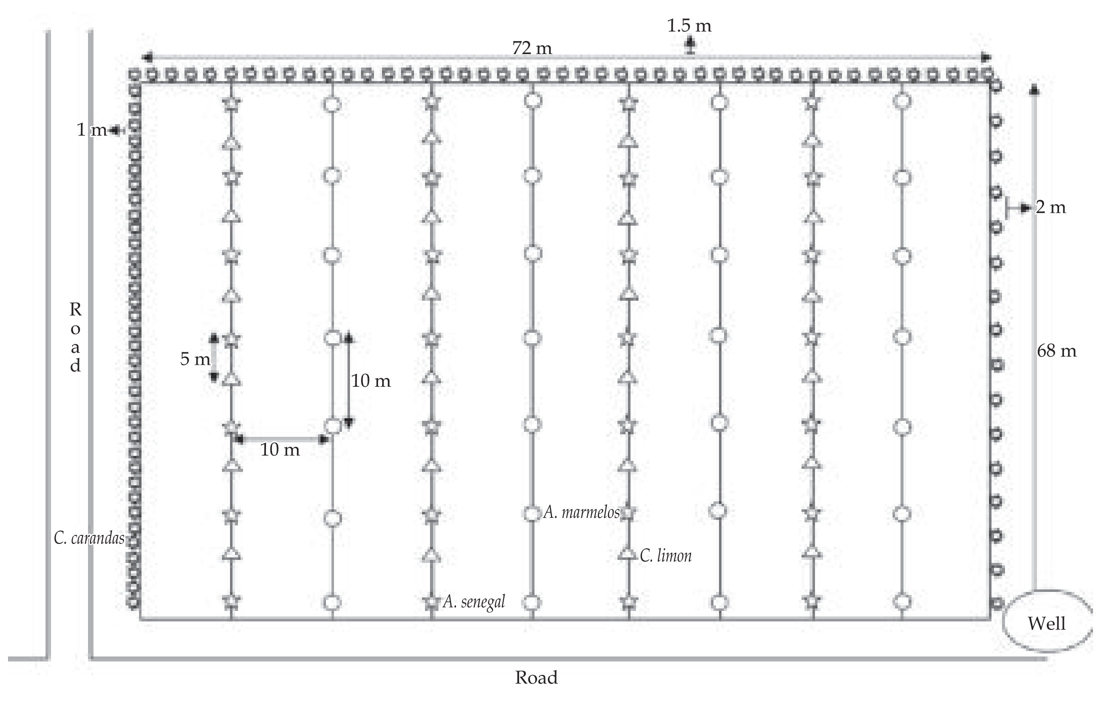

Figure 3. Design/layout of agri-horti-silviculture model at research farm of ICAR-CAFRI, Jhansi.

Table 3. Monthly distribution of rainfall (mm) during 2009-19 at ICAR-CAFRI, Jhansi.

Year	Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	7.8	0.0	0.0	2.0	10.0	11.4	163.3	149.9	136.2	69.8	12.8	14.8
2010	2.0	18.0	0.0	0.0	3.2	25.6	247.4	229.4	169.6	0.0	22.2	1.0
2011	0.0	2.4	0.0	0.0	8.4	501.0	243.0	307.4	227.0	0.0	0.0	0.0
2012	49.6	0.0	0.0	7.5	0.0	44.2	416.8	219.4	88.0	0.0	0.0	0.0
2013	1.4	118.8	5.0	0.8	0.0	156.6	430.3	473.2	29.0	139.7	0.6	19.4
2014	51.6	69.2	3.4	15.2	8.5	82.8	179.5	76.2	119.5	0.2	0.0	23.4
2015	33.0	15.0	43.0	3.1	0.0	74.6	199.8	348.8	14.0	0.0	0.0	0.0
2016	0.0	0.0	7.2	0.0	27.6	118.1	336.0	168.3	0.0	0.0	0.0	0.0
2017	17.4	0.0	0.0	0.0	28.8	116.2	241.4	152.8	90.4	0.0	0.0	0.0
2018	0.0	0.0	0.0	0.0	0.0	58.6	378.8	264.4	419.1	0.0	0.0	0.0
2019	0.0	25.2	0.1	0.0	0.0	40.8	302.1	137.3	227.7	37.9	0.0	3.0

Table 4. Survival (%) and growth of tree components after ten years of planting in agri-horti-silviculture model at research farm of ICAR-CAFRI, Jhansi.

Plant species	Survival (%)	GBH (cm)	Height (cm)	Canopy spread (m^2)
Acacia senegal	92.9	37.6	524.0	24.2
Aegle marmelos	78.6	40.3	556.4	31.9
Citrus limon	79.2	23.8	411.5	17.4
Carissa carandas	93.5	3.9 (CD)	186.4	2.1

5.3 Economic analysis

For economic analysis of the model, benefit:cost (B:C) ratio, net present value (NPV), internal rate of return (IRR) and payback period (PBP) were used as measures of economic efficiency. The B:C ratio is an economic indicator for the rate of returns per rupee invested. Reddy and Ram (2010) have opined that B:C ratio should be worked out by dividing the sum of discounted net cash flow by the establishment cost at 9% rate of interest. For calculating B:C ratio of pineapple orchard, Rymbai *et al*. (2012) divided the sum of discounted net return or cash flow by establishment cost at 9% rate of interest. However, in present study, considering the complexity and site specific conditions for gum arabic based agroforestry model on farmers' field, the B:C ratio has been worked out on annual basis and at discounted rate of 12% for whole period of 10 years by dividing total returns or cash flow from the system by total cost of working capital including cost of cultivation of intercrops and maintenance cost of agroforestry model on year to year basis. The NPV was calculated to show present worth of the model. The NPV is the principal project evaluation criterion. The NPV is merely the algebraic difference between discounted benefits and discounted costs as they occur over time. The IRR is the annual earning rate of the project. It is calculated to present the capacity of model to generate regular profit and for comparison with cost of capital. The PBP represents length of time required for the stream of cash proceeds produced by the investment to be equal to the original cash outlay i.e. the time required for model to pay for itself. The PBP of the agroforestry model was calculated to show the time period in which the model will be able to generate sufficient revenue to cover all the 10 years cost involved in different years and when this model turns profitable.

In present study, economic analysis of the agri-horti-silviculture model has been done on the basis of opportunity costs of different inputs (Kumar and Singh, 2017). Cost components for gum arabic based agri-horti-silviculture model are divided into following categories: Establishment cost (A) consisted of cost of establishment of woody perennials or tree component incurred in the beginning of the year of planting (field preparation, cost of seedlings and their plantation, plant protection, watering etc.); Operational cost (B) included the cost incurred in subsequent years for maintenance of the agroforestry model, cultivation of intercrops - seeds and fertilizers, irrigation, harvesting, threshing etc.; Total working capital (C) included the establishment cost (A) and operational cost (B); Interest (@3%) on working capital (C) gave the cost (D); Total variable cost (E) was sum of cost C and D; Rental value of the land (Rs. 8000-10000 ha^{-1}) was categorized as cost F; cost G included the Total variable cost (E) and Rental value (F); and the cost H was Risk management calculated at 10% of cost G.

For benefit-cost analysis, certain basic assumptions for input costs/outputs or returns were considered. As far as possible, prevailing unit rates for various inputs and outputs were used for calculating B:C ratio of agri-horti-silviculture model. The different unit rates used for calculation are as below:

- For establishment cost of agroforestry model, prevailing schedule of rates for digging of pits and planting, and actual cost of planting materials have been used. For maintenance of agroforestry model, prevailing rates for inputs/wages are used for different years after giving due consideration to inflation.
- For first three years, unit rate of working days was Rs. 100 per day, thereafter it was enhanced to 120 per day for 4th and 5th years, Rs. 140 per day for 6th year, Rs. 200 per day for 7th year, Rs. 250 per day for 8th to 10th years.
- The actual prevailing rates of seeds and fertilizers have been used.
- For machinery (tractor, electric motor, thresher etc.), prevailing unit rates have been used.
- For outputs/returns, prevailing market rates for fuel wood, fruits, natural gum, seeds of *A. senegal*, straw, crop yields, etc. are used.
- The B:C ratio has been worked out using the formula given below :

$$BCR = \frac{|PV\,[Benefits]|}{|PV\,[Cost]|} = \frac{\sum_{t=0}^{N} \frac{|CF_t\,[Benefits]|}{(1+i_t)^t}}{\sum_{t=0}^{N} \frac{|CF_t\,[Costs]|}{(1+i_t)^t}}$$

  Where BCR = benefit: cost ratio, PV = present value, CF = cash flow of a period (classified as benefit and cost, respectively), i = discount rate or interest rate, N = total number of periods, t = period in which the cash flows occur.

  For calculating PBP, discounted total cost was divided by annual increase in income (mean discounted benefits).

Based on the aforesaid assumptions, the year wise benefit-cost analysis on per hectare basis was carried out for agroforestry model. As an example, details of benefit-cost analysis for 1st year (2009-10) have been given in Table 5a, b, c & d. The data on summarized cost of cultivation for the study period (ten years) has been given in Table 6 and total returns in Table 7. The summarized B:C ratio has been presented in Table 8.

Table 5a. Establishment cost (A) of agri-horti-silviculture model at research farm of ICAR-CAFRI, Jhansi.

Operation/ activity	Input name	Input unit	Input taken	Unit cost (Rs.)	Cost (Rs. ha^{-1})
Field preparation					
Ploughing	Harrow	Hours	01	400.00	400
Layout and pegging	Manual	Numbers	230	0.75	173
Planting activities					
Digging of pits	230 pits	Numbers	230	4.00	920
Planting and basin preparation	230 plants	Numbers	230	2.00	460
Casualty replacement	30 plants	Numbers	30	2.00	60
Planting materials and fertilizers					
Cost of seedlings (including casualty replacement)	*A. senegal*	Number 28+7	35	2.00	70
	A. marmelos	Number 28+2	30	30.00	900
	C. limon	Number 24+5	29	5.00	145
	C. carandas	Number 150+12	162	6.00	972
FYM	Trolley	Ton	01	400.00	400
Insecticide/	Chlorpyrifos	Kg	2.5	50.00	125
herbicide	Spraying	Working day	0.5	100.00	50
Watering and maintenance					
	Watering of plants - 6 times	Working day	230 plants (6 times)	100.00	600
Miscellaneous expenses					200
Total establishment cost for 0.5 ha					**5475**

B. Cost of cultivation of intercrops

Table 5b. Cost of cultivation of summer crop (black gram) during 2009-10 (B1).

Operation/ activity	Input name	Input unit	Input taken	Unit cost (Rs.)	Cost (Rs.)
Field preparation	Harrow	Hours	01	400	400
	Cultivator	Hours	02	400	800

Seeds/Fertilizer	Manure	Ton	04	400	1600
	DAP	Kg	50	9	450
	Seeds	Kg	07	30	210
Seed sowing	Broadcast	Working days	01	100	100
Harvesting	Manual	Working days	05	100	500
Threshing, cleaning, winnowing etc.		Working days	03	100	300
Other expenses					200
Total (B1) Rs. for 0.5 ha					**4560**

Table 5c. Cost of cultivation of winter crop (mustard) during 2009-10 (B2).

Operation/ activity	**Input name**	**Input unit**	**Input taken**	**Unit cost (Rs.)**	**Cost (Rs.)**
Field preparation	Harrow	Hours	01	400	400
	Cultivator	Hours	02	400	800
Seeds/Fertilizer	Urea	Kg	50	5.6	280
	DAP	Kg	50	9	450
	Seeds	Kg	4.5	40	180
	Insecticide	L	0.4	400	160
Seed sowing	Broadcast	Working days	01	100	100
Irrigation	Canal water	Working days	03	100	300
	Charge for electric motor (5 HP)	Hours	36	7.5	270
Harvesting	Manual	Working days	04	100	400
Threshing	Mechanized	Hours	02	450	900
Cleaning, winnowing etc.	Manual	Working days	03	100	300
Other expenses					200
Total (B2) Rs. for 0.5 ha					**4740**
Total of B (B1+B2) Rs. for 0.5 ha					**9300**

C. Total Working Capital (A+B)	14775
D. Interest on Working Capital (@3%)	443
E. Total Variable Cost (C+D)	15218
F. Rental Value of the Land	4000
G. Total (E+F)	19218
H. Risk Management (10% of G)	1922
Total cost of working capital (Rs. for 0.5 ha)	**21140**

Table 5d. Returns from agri-horti-silviculture model during 2009-10.

Produce	Items	Unit	Quantity (kg)	Prevailing rates (Rs.)	Value (Rs.)
Crop yield	Black gram	Kg	284	25	7100
	Mustard	Kg	368	18	6624
By-products of crops	Black gram straw	Kg	600	2	1200
	Mustard straw	Kg	750	1	750
Output from tree component	Fruit yield	Kg	--	--	--
	Gum yield	Kg	--	--	--
	Seeds of *A. senegal*	Kg	--	--	--
Total value of output (Rs.)					**15674**
B:C ratio					**0.74**

In first year (2009-10), the cost of establishing agroforestry model (A) was Rs. 10950 ha^{-1}, total expenditures on cultivation (B) of summer (*P. mungo*) and winter crops (*B. campestris*) were Rs. 9120 and Rs. 9480 ha^{-1}, respectively. Thus, working capital was Rs. 29550 ha^{-1}. Addition of 3% rate of interest, rental value of the land (for one ha) and risk management factor @ 10% increased total cost of cultivation to Rs. 42280 ha^{-1}. The total cost of cultivation incurred during 1st year (Rs. 42280 ha^{-1}) declined in 2nd year (Rs. 25863 ha^{-1}). The comparatively higher input cost during 1st year over 2nd year was due to the establishment cost of the model (Rs. 10950 ha^{-1}). During 2nd year, the total input cost included only costs of maintenance of the model (Rs. 1660 ha^{-1}) and cultivation of intercrops (Rs. 13400 ha^{-1}). During subsequent years, increase in the cost of cultivation or working capital, owing to inflation on year to year basis, with increase in the age of the model was noticed. During entire study period, the maintenance cost of the model varied from Rs. 1380 to 1980 ha^{-1} and cost of cultivation of intercrops from Rs. 8626 to 40496 ha^{-1} (Table 6). This variation was due to the type of crops grown and cost of their cultivation. In 1st year, the model yielded total return of Rs. 31348 ha^{-1} which included

Table 6. Summarized cost of cultivation (Rs. ha^{-1}) of agri-horti-silviculture model at ICAR-CAFRI, Jhansi for ten years.

Year	Tree component: Establishment cost (Rs.)	Tree component: Maintenance cost (Rs.)	Cost (Rs.) of cultivation of intercrops: Summer	Cost (Rs.) of cultivation of intercrops: Winter	Cost (Rs.) of cultivation of intercrops: Total	Total working capital (Rs.)	Interest on working capital (i.e. C) @ 3%	Total variable cost (Rs.)	Rental value of land (Rs. ha^{-1})	Total	Risk management @ 10% of G	Total cost of working capital (Rs.)
	(A)	(A)	(B1)	(B2)	(B) = B1+B2	(C) = A+B	(D)	(E) = C+D	(F)	(G=E+F)	(H)	
2009-10	10950	--	9120	9480	18600	29550	887	30437	8000	38437	3844	42280
2010-11	--	1660	5320	8080	13400	15060	452	15512	8000	23512	2351	25863
2011-12	--	1628	8520	9744	18264	19892	597	20489	8000	28489	2849	31338
2012-13	--	1740	--	10056	10056	11796	354	12150	8000	20150	2015	22165
2013-14	--	1580	--	8626	8626	10206	306	10512	9000	19512	1951	21463
2014-15	--	1380	5780	22300	28080	29460	884	30344	9000	39344	3934	43278
2015-16	--	1780	--	26470	26470	28250	848	29098	9000	38098	3810	41907
2016-17	--	1480	--	33256	33256	34736	1042	35778	9000	44778	4478	49256
2017-18	--	1680	10120	17865	27985	29665	890	30555	9000	39555	3955	43510
2018-19	--	1980	13798	26698	40496	42476	1274	43750	10000	53750	5375	59125

Table 7. Summarized returns (Rs. ha^{-1}) from agri-horti-silviculture model at ICAR-CAFRI, Jhansi for ten years.

Year	Returns (Rs. ha^{-1}) from intercrops: Summer	Returns (Rs. ha^{-1}) from intercrops: Winter	Returns (Rs. ha^{-1}) from intercrops: Total	Returns (Rs. ha^{-1}) from trees: Tree	Returns (Rs. ha^{-1}) from trees: Fruit	Returns (Rs. ha^{-1}) from trees: Total	Total returns (Rs. ha^{-1})
2009-10	16600	14748	31348	0	0	0	31348
2010-11	14742	6940	21682	0	0	0	21682
2011-12	15360	18300	33660	96	0	96	33756
2012-13	0	19800	19800	668	1440	2108	21908
2013-14	0	18800	18800	212	2520	2732	21532
2014-15	0	47630	47630	1860	2040	3900	51530
2015-16	0	45660	45660	1588	5940	7528	53188
2016-17	0	67040	67040	4990	6640	11630	78670
2017-18	17960	24240	42200	8318	11300	19618	61818
2018-19	16620	84612	101232	13252	12800	26052	127284

Rs. 16600 (seed yield: Rs. 14200 and straw yield: Rs. 2400) from summer crop and Rs. 14748 (seed yield: Rs. 13248 and straw yield: Rs. 1500) from winter crops (Table 7). The returns from intercrops varied from Rs. 18800 to 101232 ha^{-1} during study period of 10 years, and this variation was due to the success or poor yield or failure of crop particularly in summer season. Perusal of output or returns of 10 years revealed that out of 10 seasons, summer crops either failed or performed poorly during five seasons (2012-13 to 2016-17) which affected the value of total returns from the agri-horti-

Table 8. Summary of benefit-cost analysis of agri-horti-silviculture model at ICAR-CAFRI, Jhansi for ten years.

Year	Intercrop grown		Total cost of cultivation (Rs. ha^{-1})	Total returns (Rs. ha^{-1})	Annual B:C ratio	B:C ratio (two periods of 5 years each)
	Summer	Winter				
2009-10	Black gram	Mustard	42280*	31348	0.74	0.93
2010-11	Black gram	Lentil	25863**	21682	0.84	
2011-12	Black gram	Mustard	31338	33756	1.08	
2012-13	Poor/ Failed	Mustard	22165$	21908	0.99	
2013-14	Poor/ Failed	Mustard	21463$	21532	1.00	
2014-15	Poor/ Failed	Wheat	43278#	51530	1.19	1.52
2015-16	Poor/ Failed	Wheat	41907#	53188	1.26	
2016-17	Poor/ Failed	Wheat	49256	78670	1.60	
2017-18	Green gram	Mustard	43510	61818	1.42	
2018-19	Green gram	Wheat	59125	127284	2.15	
Annualized average for 10 years			38019	50272	1.32	1.32

*Includes cost of establishment of agroforestry model in 1st year
**Includes cost of maintenance of agroforestry model during subsequent years
$ Summer crop was not sown #Summer crop was sown but failed

silviculture model. The returns from trees/woody components varied from Rs. 96 to 26052 ha^{-1}. Thus, results signifies that total returns from the model depend on the success of intercrops and yield from woody perennial components which varied from Rs. 21532 to 127284 ha^{-1} (Table 7).

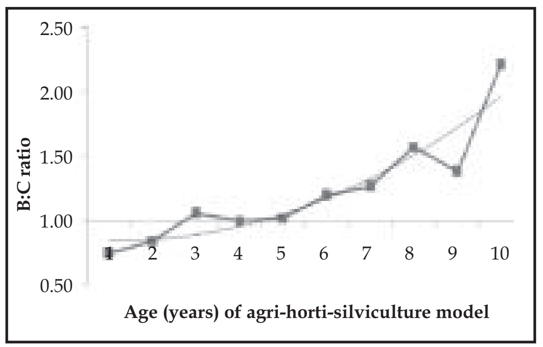

Figure 4. Variations in B:C ratio of agri-horti-silviculture model over a period of ten years.

Data on summary of undiscounted benefit-cost analysis has been presented in Table 8. It indicated that during 1st year, the annual B:C ratio was 0.74 implying that there was net loss against investment in the agri-horti-silviculture model. In 2nd year also the annual B:C ratio remained less than 1.0, and during 3rd to 5th year, it remained almost static around 1.0; thereafter, it increased considerably and reached up to 2.15 in 10th year (Table 8 and Figure 4). For first five year period, the B:C ratio was 0.93 whereas it was 1.52 for the span of second five years. The five year period was the break even point. For total 10 years period, the annualized average B:C ratio was worked out to be 1.32. Summary of discounted cost, returns and B:C ratio, NPV, IRR and PBP have been given in Table 9. To neutralize the impact of inflation, the discounted rate was assumed as 12%. The total discounted cost of model for 10 years was found as Rs. 202442 ha^{-1} and discounted total returns was found as Rs.

240656 ha^{-1}. The discounted B:C ratio was found as 1.19 for model. The NPV of model (discounted total returns-discounted total cost) reflecting the current worth of model, was found as Rs. 38214 ha^{-1}. The IRR is rate of return or profit from the model. The rate of return of the model is to be compared with cost of capital (rate of interest). In this model, the IRR was found as 18.29%, which was sufficiently above the rate of interest of 12%. Thus, the model is suitable for adoption by the smallholder farmers. On the basis of annual returns from the model, the PBP was found as 8.41 years. It implies that the total cost of the model spent in 10 years was recovered in 8.41 years and thereafter the model has started generating net profits only.

Table 9. Discounted cost, returns and B:C ratio at 12% discount rate for agri-horti-silviculture model.

Year	Discounted total cost (Rs. ha^{-1})	Discounted total returns (Rs. ha^{-1})	NPV (Rs. ha^{-1})
2009-10	37750	27989	-9761
2010-11	20618	17285	-3333
2011-12	22306	24027	1721
2012-13	14086	13923	-163
2013-14	12179	12218	39
2014-15	21926	26107	4181
2015-16	18957	24060	5103
2016-17	19894	31773	11880
2017-18	15690	22292	6602
2018-19	19037	40982	21945
Total	202442	240656	38214
Average	20244	24066	
B:C ratio at discounted rate of 12% after ten years		1.19	
IRR after ten years (%)		18.29	
PBP (years)		8.41	

5.4 Risk bearing potential and climatic resilience

The component wise returns from agri-horti-silviculture model were not always static, and it faced ups and down due to poor and/or failed summer crop, while returns from tree components increased continuously 3rd year onwards. In the study, maximum loss due to failure of summer crops was equated with the maximum returns from successful summer crop which was Rs. 17960 ha^{-1} obtained during 9th year (2017-18). Winter season crop never failed, however, returns from winter crop varied and depended on the type of crops cultivated and its performance. Despite failure of summer crop during

4th to 8th years, the annual B:C ratio either maintained around 1.0 or was more than 1.0 implying that the failed crop losses were compensated by usufructs from woody components which started giving return 3rd year onwards and horticulture component which started giving return 4th years onward (Figure 5). Perusal of the data suggested that tree/fruit components reduced the PBP of the model exhibiting its potential to act as a sink for climate related risks in agricultural production system. Production of *gum-arabic* from *A. senegal* can also help in covering up the risk and may provide revenue. In present study, *A. senegal* started yielding gum naturally 6th years onward. Increase in its production was noticed with the age of the model. This gum is highly valuable and fetches Rs. 600-800 kg^{-1} in our country. Thus, more returns from *A. senegal* in form of *gum-arabic* is expected from agri-horti-silviculture model in future. Further, results of present study showed that this smallholding model could compensate 100% loss of failed summer crop after 8.41 years (Figure 6). In our study, summer crops (*P. mungo* or *V. radiata*) always remained at risk due to abnormal monsoon rain which can create insecurity in terms of food supply. Multiple component based agroforestry system can successfully combat food insecurity by responding to challenges related to climate change.

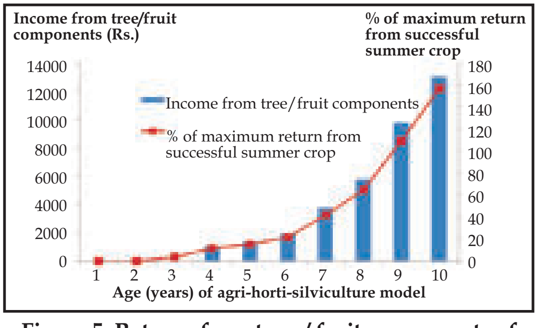

Figure 5. Returns from trees/ fruit components of agri-horti-silviculture model.

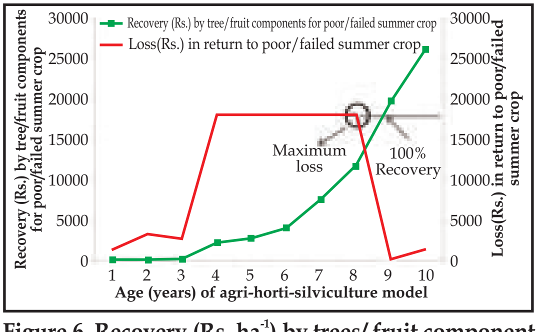

Figure 6. Recovery (Rs. ha^{-1}) by trees/ fruit component for losses due to poor/ failed summer crop in agri-horti-silviculture model.

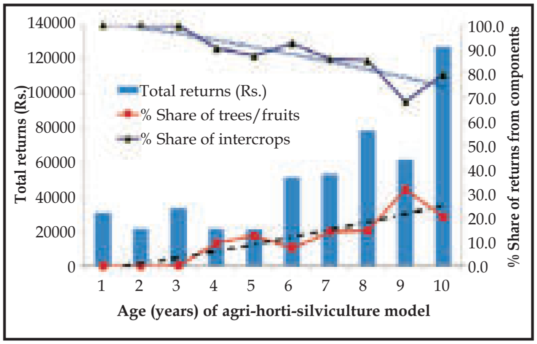

Figure 7. Share of different components of agri-horti-silviculture model in total returns (Rs. ha^{-1}).

Irrespective of intercrops, general decline in per cent share of returns from intercropping in total returns from agri-horti-silviculture model was noticed. After 10 years, the decline was recorded up to 20% which was compensated fully by increasing share of tree/woody components of the model (Figure 7). After 10 years, the annual B:C ratio of 2.15 indicates that a farmer may earn Rs. 2.15 against per rupee invested in agri-horti-silviculture model on his farm, and this rate of returns is likely to increase further with increase in the returns from tree/woody components with the age of the model. In broader sense, system started yielding eminently 6th years onward as reflected in terms of B:C ratio.

CHAPTER 6 Summary and Recommendations

The full potential of gum arabic (*A. senegal*) tree has not been showcased despite its wide occurrence and presence in Indian subcontinent particularly in arid and semi-arid regions. Bundelkhand region, representing typical semi-arid climate and undulating landscape, offers suitable conditions for production of gum arabic which may provide livelihood security to smallholders and poverty stricken farmers. Large scale plantations in the form of agroforestry will also help in increasing production base of *gum-arabic*, which is declining due to over exploitation of existing trees and adversely affecting national and international trade. Integration of *A. senegal* in agroforestry appears to be the best approach for upscaling its plantation on farmland. Based on the financial analysis of gum arabic based agroforestry model, following summarized recommendations are put forth for harnessing its full potential:

- The cost of establishing multiple components including gum arabic based agroforestry model is Rs. 10950 ha^{-1}. The maintenance cost of this agroforestry model varies from Rs. 1380 to 1980 ha^{-1} year^{-1} during a period of 10 years.
- The cost of cultivation of intercrops (black gram or green gram in summer and mustard or wheat in winter) ranges from Rs. 8626 to 40496 ha^{-1} year^{-1} during a period of 10 years. Variation in cost of intercrop cultivation was due to success or failure and choice of crops.
- The returns from intercrops varies from Rs. 18800 to 101232 ha^{-1} year^{-1} during a period of 10 years. Variation in returns from intercrops was due to success or poor yield or failure of crop particularly in summer season.
- The returns from trees/woody components varies from Rs. 96 in 3rd year to 26052 ha^{-1} in 10th year. In general, returns from woody/tree component increased with increase in the age of the agroforestry model.
- Total returns from gum arabic based agroforestry model varies from lowest Rs. 21532 ha^{-1} in 5th year to Rs. 127284 ha^{-1} in 10th year.
- The B:C ratio was <1.0 in first two years, remained static about 1.0 during 3rd to 5th year and thereafter, increased considerably reaching to 2.15 at the end of 10th year of the productive phase of the gum arabic based agroforestry model.
- Inclusion of horticultural components reduced break even point to five years for agroforestry model.
- The B:C ratio of 1.26 and 1.60 during 7th and 8th years despite failure of summer crop exhibited risk bearing potential and climatic resilience of the agroforestry model.

- At the end of 10th year, the rate of return was 2.15 per rupee invested in agroforestry model which proved its potential to enhance income of the farmers in adverse climatic conditions faced in arid and semi-arid regions.

In nutshell, *A. senegal* or better known as gum arabic has exhibited its potential for integration in agroforestry systems in Bundelkhand region. Financial analysis revealed that multi-components gum arabic based agroforestry model can offer income of Rs. 127284 ha^{-1} for an investment of Rs. 59126 ha^{-1} with B:C ratio of 2.15 after 10 years. This agroforestry model at central farm of ICAR-CAFRI, Jhansi remains a hot spot and has been visited by many farmers' delegation, dignitaries, experts and policymakers including members of Research Advisory Committee (RAC), Quinquennial Review Team (QRT), Annual workshop, group of Scientists and administrators from Asian and African countries (Plate 9).

Plate 9. Expert-interaction during field visits by dignitaries including members of RAC, QRT, Annual Workshop, Scientists & Policymakers from Asian and African countries on gum arabic based agroforestry models at ICAR-CAFRI, Jhansi.

Conclusively, *A. senegal* need to be included in State Forest Plantation Programmes of the Uttar Pradesh and Madhya Pradesh, as the Bundelkhand region offers good scope and suitable conditions for its successful plantation on arable as well as forest lands.

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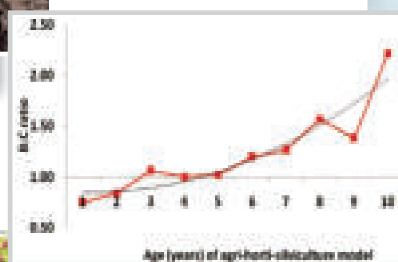
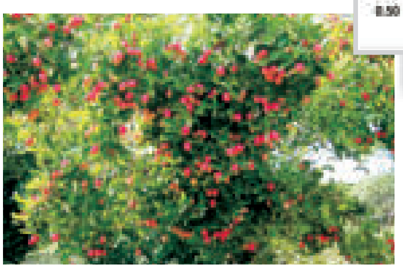
Swachh Bharat Abhiyan

एक कदम स्वच्छता की ओर

Agrisearch with a Human touch





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