Crop Diversification *with* Tropical Tuber Crops

for higher yield, income and soil health

भाकृअनुप – केंद्रीय कंद फसल अनुसंधान संस्थान
श्रीकार्यम, तिरुवनंतपुरम 695017, केरलम, भारत

ICAR-CENTRAL TUBER CROPS RESEARCH INSTITUTE
Sreekariyam, Thiruvananthapuram - 695 017, Keralam, India

Crop diversification with tropical tuber crops for higher yield, income and soil health

भाकृअनुप
ICAR

भाकृअनुप – केंद्रीय कंद फसल अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद)
श्रीकार्यम, तिरुवनंतपुरम 695017, केरलम, भारत

ICAR-CENTRAL TUBER CROPS RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
Sreekariyam, Thiruvananthapuram - 695 017, Keralam, India

ICAR-Central Tuber Crops Research Institute
(Indian Council of Agricultural Research)
Sreekariyam, Thiruvananthapuram 695 017, Keralam, India
Tel: (91) (471) 2598551 to 2598554
E-mail: director.ctcri@icar.org.in
Website: https://www.ctcri.org

Published by
Dr. G. Byju
Director

Editors
G. Suja
M. Nedunchezhiyan
D. Jaganathan
G. Byju
S. Sunitha

Technical bulletin Series No. TB-124/2026

July 2026

Citation
Suja, G., Nedunchezhiyan, M., Jaganathan, D., Byju, G. and Sunitha, S. 2026. Crop diversification with tropical tuber crops for higher yield, income and soil health. Technical Bulletin No. TB-124/2026, ICAR-Central Tuber Crops Research Institute, Sreekariyam,Thiruvananthapuram, Keralam, India, 76p.

Design, Layout & Printing
Aden Digital Signage, Thiruvananthapuram
Mob: +91 9605206323, Email: adentvm2018@gmail.com

Contents

ICAR-Central Tuber Crops Research Institute
Sreekariyam 695 017, Thiruvananthapuram, Keralam, India

Dr. G. Byju
Director

Phone: 0471- 2598431
Email: director.ctcri@icar.org.in

From the Director

Tropical tuber crops occupy a unique and strategic position in Indian agriculture by contributing simultaneously to food and nutritional security, livelihood enhancement, climate resilience, and sustainable agricultural development. These crops are increasingly recognized as future crops because of their remarkable adaptability to marginal lands, tolerance to climatic stresses, high biological productivity, and diverse food, feed, industrial and nutritional uses. Their integration into diversified farming systems offers enormous opportunities to enhance productivity, profitability, resource-use efficiency, and environmental sustainability.

Crop diversification has emerged as a key strategy for building resilient agricultural systems in the face of climate change, shrinking landholdings, declining soil health, and increasing production risks. Integrating tropical tuber crops with plantation crops, fruit crops, annual field crops and sequential cropping systems enables farmers to maximize land utilization, improve soil fertility, diversify income sources and reduce production risks. The scientific evidence generated over several decades by ICAR-Central Tuber Crops Research Institute clearly demonstrates that well-designed tuber crop-based cropping systems significantly improve farm productivity, profitability and sustainability.

This technical bulletin brings together the extensive research findings generated by ICAR-CTCRI on crop diversification involving cassava, sweet potato, yams, taro, elephant foot yam and other tropical tuber crops. It presents scientifically validated intercropping and sequential cropping models, production technologies, management practices and practical recommendations suitable for different agro-ecological situations. The publication is intended to serve as a ready reference for researchers, extension professionals, students, development agencies, policy planners and progressive farmers interested in promoting sustainable and climate-smart agriculture.

I sincerely appreciate the dedicated efforts of the editors and all scientists whose research contributions over the years have made this publication possible. I am confident that this bulletin will facilitate wider adoption of tropical tuber crop-based diversified farming systems, strengthen climate-resilient agriculture, improve soil health, enhance farmers' income and contribute meaningfully to the realization of Viksit Bharat 2047 through sustainable agricultural transformation.

I hope this publication will inspire researchers, extension agencies and farmers to harness the immense potential of tropical tuber crops for developing productive, profitable and environmentally sustainable farming systems.

G. Byju
Director

July 2026

1. Introduction

Tropical tuber crops including cassava, sweet potato, yams, taro, elephant foot yam and a few other crops represent a strategic, yet underutilized component of India's food and nutrition landscape. They support 200 million Indians for food and livelihoods, generating an annual market value of around ₹130 billion. These crops are hardy, climate resilient and high yielding per unit area, thriving on marginal soils with minimal inputs, while providing a dependable source of calories, dietary fibre, vitamins and minerals. In the face of climate variability, the need for nutritional security, enhanced rural livelihoods and crop diversification, tropical tuber crops offer a unique opportunity to strengthen India's agricultural resilience, reduce import dependence for starch and processed foods, and empower smallholder, tribal and other nature dependent farmers.

The Table 1 presents the area, production, and productivity of tropical tuber crops in the world vis-à-vis India for 2023. In India, tropical tuber crops were cultivated in 0.406 million ha, accounting for 0.75% of the global area, with a total production of 10.11 million tonnes (1.85% of global production). The five major tropical tuber crops produced are cassava, sweet potato, elephant foot yam, yams, and taro, with an average productivity of 24.90 t/ha well above the global average of 10.17 t/ha (FAOSTAT, 2023).

Table 1. Area, production and productivity of tropical tuber crops in the world vis-à-vis India

Crop	Area (million ha)		Production (million tonnes)		Productivity (t/ha)	
	World	India	World	India	World	India
Cassava	32.21	0.166	333.68	5.93	10.35	35.77
Sweet potato	7.57	0.110	93.51	1.28	12.35	11.71
Elephant foot yam	-	0.040	-	0.98	-	24.74
Yams	10.60	0.030	89.34	0.81	8.42	27.00
Taro	2.40	0.040	18.07	0.61	7.52	15.30
Other crops	0.75	0.020	10.02	0.40	13.36	20.00
Total	**53.53**	**0.406**	**544.62**	**10.11**	**10.17***	**24.90***

Source: FAOSTAT (2023);*-Average of all crops

These crops can be grown under warm humid conditions of tropical as well as sub-tropical agro-ecosystem. They played a key role in the diet of early human being before evolution of settled agriculture. Till today, these crops ensure food security to millions of people in the tropical and subtropical countries either as stable or subsidiary food for about one fifth of the world population. Tuber crops contribute approximately 6% of the global dietary energy supply and are valuable sources of β-carotene, antioxidants, dietary fibre, and essential minerals. They exhibit high biological efficiency and possess the ability to tolerate drought, shade, flooding, and moderate salinity. Their adaptability to marginal environments, low-input systems, and adverse soil and climatic conditions has led to their recognition as 'climate-resilient' or 'future crops.' In addition to their nutritional importance, tuber crops have significant industrial applications, including the production of starch, sago, alcohol, liquid glucose, and vitamin C. They also serve as raw materials for poultry and animal feed and possess notable medicinal properties.

Strategic role of tropical tuber crops in crop diversification

Crop diversification involving tropical tuber crops is increasingly recognized as a strategic approach to building resilient and sustainable agricultural systems in tropical and subtropical regions. Traditionally, farming systems in many parts of Asia, Africa, and Latin America have been dominated by a few staple cereals. However, overdependence on such narrow cropping patterns often exposes farmers to risks arising from climate variability, market fluctuations, and pest or disease outbreaks. Integrating tuber crops such as cassava, sweet potato, yams, and taro into these systems offers a practical and effective means of diversification.

Tropical tuber crops are uniquely suited to marginal environments. For instance, cassava is widely cultivated in parts of sub-Saharan Africa because of its remarkable tolerance to drought and poor soils. Even under erratic rainfall conditions, it can produce reasonable yields, making it a dependable 'food security crop.' Similarly, sweet potato is grown extensively in countries like India and China due to its short duration and high nutritional value, particularly orange-fleshed varieties rich in β-carotene. In West Africa, yam cultivation is deeply embedded in cultural and economic systems, with festivals and traditional practices centered around its harvest.

Crop diversification with tubers also enhances farm-level resilience. For example, in rainfed farming systems of peninsular India, farmers often intercrop cassava or sweet potato with pulses or maize. This not only improves land-use efficiency but also ensures at least one successful harvest in case of adverse weather. In coastal and wetland ecosystems, taro is commonly cultivated in low-lying fields where other crops may not thrive, thereby expanding the productive use of land resources.

From an economic perspective, tuber crops contribute to both subsistence and commercial agriculture. Cassava, for example, serves as a raw material for starch, animal feed, and bioethanol industries in countries like Thailand and Nigeria. Sweet potato is increasingly used in processed foods, bakery products, and health foods, creating new market opportunities for farmers. Such value addition strengthens rural livelihoods and promotes agro-industrial linkages. Nutritionally, tuber crops play a vital role in addressing hidden hunger. While they are primarily energy-rich, certain varieties, such as biofortified sweet potato help combat vitamin A deficiency. Their inclusion in diversified cropping systems supports balanced diets and improves household food security.

In the context of climate change and sustainable development, the role of tropical tuber crops becomes even more significant. Their adaptability, low input requirements, and multiple uses make them ideal components of climate-smart agriculture. Thus, promoting crop diversification through tuber crops is not merely an agronomic choice but a holistic strategy for ensuring ecological balance, economic stability, and nutritional well-being.

Crop diversification with tropical tuber crops (like cassava, sweet potato, yams and aroids) plays a major role in strengthening agricultural systems, especially in tropical regions. Its significance can be understood across several dimensions as given below.

i **Food and Nutritional Security:** Tropical tuber crops such as cassava, sweet potato, yams, taro etc. are rich in carbohydrates and, in some cases, vitamins and minerals. Including them in cropping systems ensures a stable and diverse food supply, helping to reduce dependence on cereals alone.

ii. **Climate Resilience:** These crops are highly tolerant to drought, poor soils, and erratic rainfall. For example, cassava can survive under harsh conditions where other crops fail. Diversifying with such crops reduces the risk of total crop failure under climate stress.

iii. **Income Generation and Livelihood Support:** Tuber crops have multiple uses (food, feed, industrial raw material), creating opportunities for farmers to earn income through local markets and value-added products like starch and flour.

iv. **Efficient Resource Utilization:** Tropical tuber crops can grow in marginal lands with minimal inputs. Their inclusion helps to utilize land, water, and nutrients more efficiently, especially in mixed or intercropping systems.

v. **Soil Health Improvement:** Some tuber crops improve soil structure due to their root systems. When integrated into crop rotations, they help to break pest and disease cycles and enhance soil fertility.

vi. **Crop Diversity and Risk Management:** Diversification reduces reliance on a single crop, thereby spreading risk. If one crop fails due to pests, diseases, or weather, tuber crops can act as a backup.

vii. **Industrial and Export Potential:** Cassava and sweet potato are used in starch, alcohol, and processed foods, contributing to agro-industrial development and export earnings.

viii. **Cultural and Dietary Importance:** In many tropical regions, tuber crops are staple foods and part of traditional diets, supporting food habits and cultural practices.

Research and validation of crop diversification with tropical tuber crops

Research on crop diversification involving tropical tuber crops is driven by the urgent need to transform conventional, risk-prone farming systems into resilient, productive, and nutritionally secure systems. In many tropical regions, agriculture still relies heavily on a narrow range of staple crops, making it vulnerable to climatic stress, soil degradation, and market instability. Expanding the role of tuber crops such as cassava, sweet potato, yam, and taro offers a scientifically grounded pathway to address these challenges, but it requires focused research to unlock their full potential.

One of the primary rationales lies in climate variability and resource constraints. Tropical tuber crops are inherently tolerant to drought, poor soils, and erratic rainfall, yet their productivity remains below potential due to limited scientific intervention. Research is needed to develop high-yielding, stress-tolerant, and pest-resistant varieties suited to diverse agro-ecological conditions.

Another key rationale is the underutilization of these crops in formal agricultural systems. Despite their importance in subsistence farming, tuber crops have historically received less research attention compared to cereals. This gap calls for systematic studies on agronomy, crop physiology, and breeding to integrate them effectively into modern farming systems. There is also a strong rationale linked to nutritional security. While tubers are energy-rich, research can enhance their nutritional profile-for example, improving micronutrient content in sweet potato or reducing anti-nutritional factors in cassava. Such efforts align with global goals of combating malnutrition and hidden hunger.

Economic considerations further justify research. With growing demand for processed foods, starch, and bio-based products, tuber crops have emerging industrial value. Research into value addition, storage, processing technologies, and market linkages is essential to improve farmer incomes and expand value chains. The importance of this research becomes evident when considering sustainability and resilience. Diversified cropping systems that include tuber crops can stabilize yields under adverse conditions, reducing the risk of total crop failure. Scientific research helps identify optimal cropping patterns, intercropping systems, and crop rotations involving tubers.

Research on cropping systems also contributes to efficient resource use. Studies on water management, nutrient cycling, and soil health in tuber crop based systems can enhance productivity, while conserving natural resources. For instance, integrating tubers into low-input or marginal lands can bring otherwise unproductive areas into cultivation. Another critical area is pest and disease management. Tuber crops are affected by specific pests and pathogens, and research is necessary to develop integrated management strategies that are both effective and environmentally sustainable in systems involving tuber crops.

By generating technologies that increase yield, reduce costs, and enable value addition, it enhances the profitability of farming systems. Finally, research on crop diversification involving tropical tuber crops contributes to policy formulation and agricultural planning. Evidence-based insights can guide governments and institutions in promoting diversified, climate-resilient agriculture through targeted interventions and support systems.

2. Research Facilities and Methodology

A strong research framework and evidences are essential to successfully promote crop diversification with tropical tuber crops such as cassava, sweet potato, yams and aroids. This involves well-equipped facilities and multidisciplinary methodologies that integrate field-level experimentation with advanced scientific tools. A brief account of the research methodology followed at ICAR-Central Tuber Crops Research Institute, Keralam, India, is given in this section.

Research Farm

ICAR-CTCRI, Thiruvananthapuram, Keralam

The field investigations were carried out at the ICAR-Central Tuber Crops Research Institute, located in Thiruvananthapuram, Keralam. The institute is geographically situated at 8°29′ N latitude and 76°57′ E longitude, at an elevation of 52 m above mean sea level. The region experiences a humid tropical climate, which is highly suitable for the cultivation and evaluation of tropical tuber crops.

The experimental site receives an average annual rainfall of 1672 mm, predominantly from the southwest and northeast monsoons. The mean annual maximum and minimum temperatures are 31.82°C and 23.82°C, respectively, with a high relative humidity averaging 85.97%, creating favorable conditions for year-round crop growth.

The soil of the research farm is classified as a well-drained acid Ultisol, with a pH of 4-5.5. It is characterized by low available nitrogen, high available phosphorus, and low to medium available potassium. The soil also contains moderate organic carbon, indicating fair soil fertility status with scope for nutrient management interventions.

ICAR-CTCRI, Regional Station, Bhubaneswar, Odisha

Field experiments were also conducted at the Regional Station of the ICAR-Central Tuber Crops Research Institute located in Bhubaneswar, Odisha. This centre represents the eastern coastal agro-ecological zone of India and provides ideal conditions for evaluating tropical tuber crops under warm and humid environments.

The station is situated approximately at 20°15′N latitude and 85°52′E longitude, with an elevation of about 25 m above mean sea level. The climate of the region is tropical humid, characterized by hot summers, a pronounced monsoon season, and mild winter. The average annual rainfall ranges between 1400 and 1600 mm, most of which is received during the southwest monsoon (June-September). The mean annual maximum temperature ranges from 32°C to 36°C, while the minimum temperature varies between 15°C and 22°C. Relative humidity remains high for most of the year, especially during the cropping season.

The soils of the experimental site are predominantly lateritic to red loamy in nature, well-drained, and slightly acidic to neutral in reaction. These soils are generally low to medium in available nitrogen, medium in phosphorus, and medium to high in potassium, with moderate organic carbon content. Such soil conditions are suitable for studying nutrient management and crop performance of tuber crops under coastal plain conditions.

Laboratory Facilities

Laboratories support detailed scientific analysis, including:

- Soil testing/Agronomy labs for analysis of nutrient status and fertility management
- Plant physiology labs to study growth, photosynthesis, and stress responses
- Food quality labs to analyze proximate composition, mineral contents, and anti-nutritional factors

Research Methodology

Field Experiments

- Randomized Block Design (RBD) and Split-plot designs are commonly used
- Evaluation of different cropping systems models
- Multi-location trials to test performance under varied environments

Agronomic Studies

- Optimization of planting time, spacing, and nutrient management
- Water-use efficiency studies under rainfed and irrigated conditions
- Weed and soil management practices

Cropping Systems Research

- Designing diversified models (e.g., tuber + cereal + pulse systems)
- Resource-use efficiency and sustainability assessment
- On-farm trials involving farmers (participatory research)

Socio-Economic Analysis

- Cost-benefit analysis of diversified systems

- Adoption studies and farmer perception surveys
- Market and value chain analysis for tuber crops

Well-developed research facilities combined with robust, multidisciplinary methodologies are essential to harness the full potential of tropical tuber crops in diversified farming systems. Such an approach ensures not only higher productivity, but also sustainability, resilience, and improved livelihoods for farmers.

3. Intercropping Systems of Tuber Crops in Perennials

Feeding about two billion of people, tropical tuber crops such as cassava, sweet potato, yams, and aroids rank third after cereals and legumes. They are energy-rich, nutrient-dense, and highly adaptable. Their resilience and versatility support both food security and industrial uses.

Crop diversification, with a focus on multiple cropping strategies like intercropping and sequential cropping, is a viable adaptation strategy in the context of climate change. Intercropping tropical tuber crops like cassava, greater yam, lesser yam, elephant foot yam, tannia and arrowroot with plantation/fruit/tree crops like coconut, banana, rubber will enable sustainable livelihoods, nutritional security, prospects for value addition and doubling farmers income under climate change.

Tropical tuber crops: a popular choice as under-storey crops in plantations

Tuber crops such as cassava and sweet potato are sun-loving, with starch accumulation in their underground parts closely linked to leaf photosynthesis (Ghosh, 1994). Shading markedly delays tuberization in cassava (Kasele et al., 1984; Ramanujam et al., 1984) and drastically reduces sweet potato yield, with reductions of up to 94% under heavy shade (Nelliat and Bhat, 1979; Zara et al., 1982; Martin, 1985). Yield losses of 32-92% have also been reported under coconut canopy (Zara et al., 1982). In contrast, elephant foot yam (*Amorphophallus* sp.) and tannia (*Xanthosoma* sp.) are relatively shade-tolerant, while yams (*Dioscorea* sp.) are often cultivated in polyculture systems.

Most of the plantation crops occupy the land for several years and utilize the natural resources only to a very limited extent producing less than 10% of the potential dry matter production in the tropics (Nelliat et al., 1974). Tropical tuber crops viz., cassava, greater yam, lesser yam, elephant foot yam, tannia and arrowroot can be cultivated in association with plantation crops like coconut, arecanut, oil palm, coffee, rubber and fruit crops like banana, mango, litchi etc., as these crops are adapted to the same ecological conditions as tree crops (Nayar and Suja, 2004; Suja and Nedunchezhiyan, 2018; Nedunchezhiyan et al., 2022; Byju et al., 2023). In such a system, the main crop provides cash income, tuberous intercrops serve as high energy secondary staple to the farm family and feed for farm animals, behave as insurance crops against risk and natural calamities, enhance the resource use efficiency, ensure food security, augment net income and enhance employment opportunities. The scope of such crop associations, growth performance and production potential of tuber crops in such systems, management practices for realizing higher tuber yield and economic feasibility of the systems are dealt with in this chapter.

Coconut based intercropping systems

When planted at a spacing of 7.5 m × 7.5 m, coconut palms utilize 25% of land area effectively and intercept about 40-50% of the solar radiation at mature stage (Nair and Balakrishnan, 1976; Nayar and Suja, 2004; Nedunchezhiyan et al., 2008a) leaving 75% area for intercropping. A low evaporative demand and reduced maximum temperatures under a coconut plantation provide scope for successful cultivation of subsidiary crops as intercrops. Performance of cassava, yams (greater yam, lesser yam and white yam), elephant foot yam, tannia and arrowroot as intercrops in coconut garden has been thoroughly researched and production technologies for these crops under intercropping situation has been standardized (Nayar and Suja, 2004; Suja, et al., 2004; Suja, 2005) (Fig. 1).

Depending upon the age of the coconut palms the option of tuber crops for intercropping varies (Table 2). Experimental evidences indicated that yield was promoted by 5-15% in coconut under intercropping with tuber crops. Of the various tuber crops, arrowroot produced higher rhizome yield (7%) under intercropping. The yield reduction was lowest for elephant foot yam (11%) followed by taro (12%), lesser yam (17%) and greater yam (20%). Yield reduction was comparatively higher for sweet potato (47%) followed by cassava (33%) and white yam (29%) (Nayar and Suja, 2004). Ravindran (1997) reported that cassava, banana, elephant foot yam and vegetable cowpea can be raised successfully and economically as intercrops in mature coconut garden, applying half the recommended dose of N&P and full dose of K without much competition for nutrients, moisture and light. Management practices for intercropping root and tuber crops in coconut gardens are given in Table 3.

Table 2. Option of tuber crops for intercropping in coconut gardens at various stages

Age of coconut palms	Tuber crops
< 8 years	Cassava, Elephant foot yam, Yams
8-25 years	Elephant foot yam, Taro, Tannia, Arrowroot
> 25 years	Cassava, Elephant foot yam, Taro, Tannia, Yams, Arrowroot and Chinese potato

Source: Edison et al. (2006)

Cassava as an intercrop: The performance of cassava as an intercrop with coconut has been extensively researched in India. Cassava varieties like H-165, Sree Visakham (H-1687) and Sree Sahya (H-2304) can be grown satisfactorily with an average tuber yield of about one kg/plant by applying NPK doses of 75:75:75 kg/ha. The economic evaluation of coconut-based intercropping at CPCRI, Kerala, under rainfed conditions showed that cassava was second best after elephant foot yam when added net return per ha was considered (Das, 1984).

Table 3. **Management practices for root and tubers intercropped in coconut gardens**

Intercrop	Time of planting	Suitable variety	Method of planting, spacing and plant population per ha	Manures		Duration (months)
				FYM (t/ha)	NPK (kg/ha)	
Cassava	May-June	Sree Visakham H-165 Sree Vijaya Sree Reksha Sree Pavithra Sree Annam Sree Manna	Mounds 90×90 cm (9000 plants)	9	50:50:100	8-10
Elephant foot yam	March-April	Sree Padma Gajendra	Pits 90×90 cm (9000 plants)	20	26:20:33	8-9
Greater yam	April-May	Sree Keerthi	Pits 90×90 cm (9000 plants)	9	80:60:80	8-9
Lesser yam	April-May	Sree Latha	Pits 75×75 cm (12000 plants)	8	60:30:60	7
White yam	April-May	Sree Priya	Pits 90×90 cm (9000 plants)	9	80:60:80	8-9
Arrowroot	May-June	Local selection Sree Aadya	Raised beds 30×15 cm (130000 plants)	10	50:25:75	9-10

Source: Nayar and Suja (2004)

Production potential of cassava var. Sree Visakham intercropped in coconut gardens were investigated in detail by Nayar (1986). Nayar and Sadanandan (1992) reported that N application for cassava intercropped in coconut gardens can be reduced to half (50 kg/ha)) of the sole crop requirement (100 kg/ha).

Nedunchezhiyan et al. (2008a) evaluated growth and productivity of genetically improved cassava varieties under 30-33 year old coconut palms. Plant height; number of storage roots per plant; length, girth, and weight of storage roots; yield per plant; and storage root yield per ha varied as follows among varieties: 158-182 cm, 5.0-6.8, 21.7-23.9 cm, 9.2-10.8 cm, 104-141.8 g, 780-1069 g/plant and 9.64-13.2 t/ha, respectively. The 50–69% reduction in storage root yield of cassava varieties under coconut palms relative to sole-crop yield under open sunlight was mainly due to a 50% reduction in net photosynthetic rate under coconut palm shade (Nedunchezhiyan et al., 2012a). The mean coconut yield varied between 82 and 84 numbers per tree, as the cassava intercropping, regardless of varieties, did not affect growth and yield of the coconut trees. In the Philippines, integration of root crops such as cassava with coconut, using adequate fertilizers, is a popular intercropping practice (Das, 1991).

Sweet potato as an intercrop: Sweet potato being an insurance crop against natural calamities, has more flexibility in adjusting in any cropping system and hence can be grown as an intercrop in plantation crops (Nedunchezhiyan et al., 2008b). In West Coast of India, sweet potato is grown as an intercrop in coconut (*Cocos nucifera* L.) and arecanut (*Areca catechu* L.) gardens, both at the pre-bearing and mature phases. However, in mature stands of coconut and arecanut, productivity of sweet potato is drastically reduced for want of light. Similarly in East Coast of India, intercropping sweet potato did not affect the growth and yield of coconut and in newly established coconut gardens of Odisha, sweet potato variety Samrat proved profitable for intercropping (Nedunchezhiyan et al., 2007). Nedunchezhiyan et al. (2008b) reported relatively low sweet potato tuber yield in established coconut garden. However, it produced net return of $ 206.1/ha with a benefit:cost ratio of 1.60.

Yam as an intercrop: In young coconut plantations (<10 years), and mature coconut plantations (>25 years) plenty of sunlight is available, which allow the cultivation of intercrops. In order to utilize these natural resources efficiently along with soil nutrients and water, easily adaptable and cultivable yams and aroids are recommended (Nayar and Suja, 1999). The performance of yams, particularly white yam (*Dioscorea rotundata*) as intercrop in coconut garden was assessed by Nayar and Suja (1999) and Suja (2001).

African white yam (*Dioscorea rotundata)* is a profitable and viable intercrop in coconut plantations. Agronomic package and INM schedule, has been developed, for white yam intercropping in coconut gardens. Treatment of white yam setts of 100 g with thiourea 2% induced early, synchronized and higher sprouting (Suja et al., 2003a). Planting white yam setts of 200 g at a spacing of 90 × 90 cm (9000 plants per ha of coconut garden) resulted in optimum yield (16.52 t/ha), quality tubers, additional employment (318 man days per ha) and higher profit (₹19,363 per ha) (Suja et al., 2003b). Conjoint use of coir pith compost @ 5 t/ha and N, P_2O_5, K_2O @ 80:60:80 kg/ha is recommended for maintaining high yield (24.61 t/ha) of good quality tubers and net return (₹ 36,187 per ha) when continuously intercropped in coconut gardens (Suja et al., 2004).

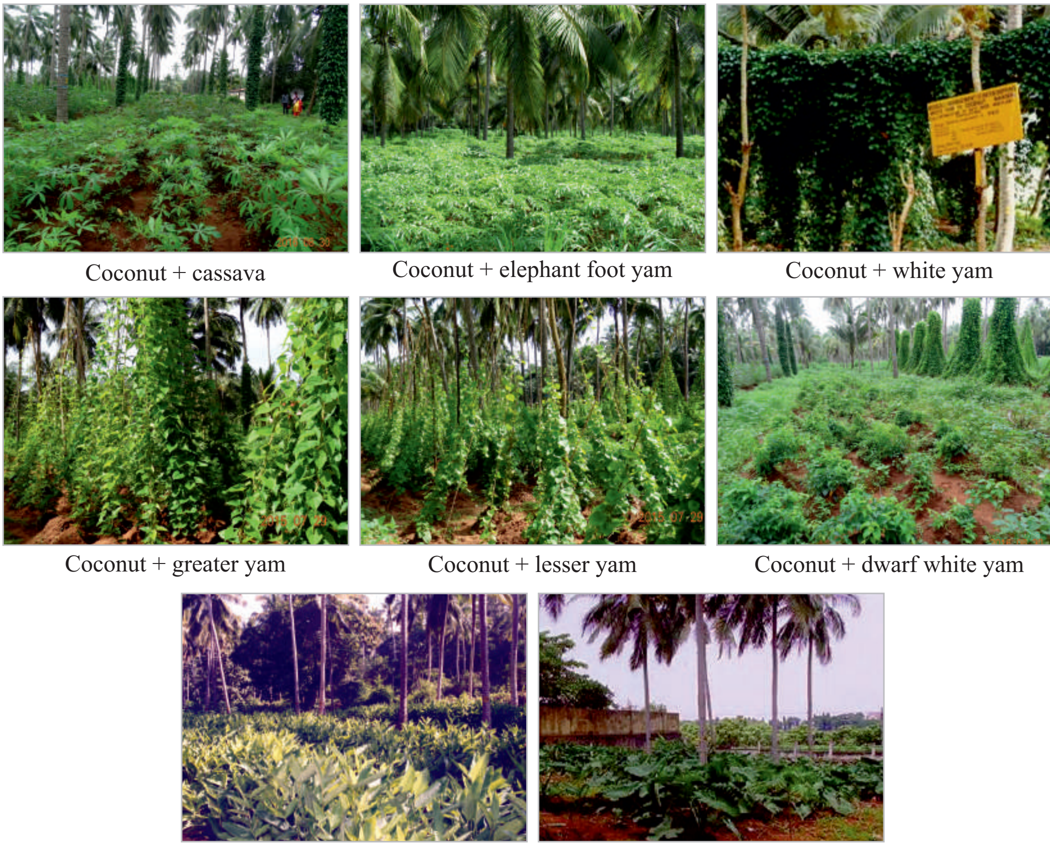
In eastern India, in an established coconut garden (cv. West Coast Tall) in the age group of 25-30 years, Nedunchezhiyan et al. (2008c) reported that trailing genotypes of *Dioscorea* viz., Sree Priya (*D. rotundata*) and Sree Keerthi (*D. alata*) could be profitably intercropped. They further found that higher tuber length, mean tuber girth and tuber yield/plant were obtained with larger greater yam sett size (200 g) planted at wider spacing under established coconut garden. Intercropping of greater yam did not affect the growth and nut yield of coconut. They found an increase in net profit to the tune of ₹ 9,600-10,260/ha with the intercropping of trailing type of *Dioscorea*. The highest net returns of ₹ 37,750/ha and benefit:cost ratio of 2.06 was realized in the above agronomic package (Nedunchezhiyan et al., 2008c).

Elephant foot yam as an intercrop: Elephant foot yam is very well adapted to fairly long moist growing season and relatively low temperature, which usually prevailed under perennial plantations as in coconut gardens. In a two years trial at Kasaragod, Kerala, India the performance of elephant foot yam was better under shaded conditions compared to open. From the soil temperature measurements made during the crop period it was observed that the soil temperature remained high during September to November (post-rainy season). As a result of high temperature in the soil, the crop attained senescence at a much earlier stage resulting in poor productivity in the open. However, under shaded conditions the soil temperature remained relatively low and resulted in better productivity of the crop (CPCRI, 2011).

Moreover, a multi-species cropping system consisting of coconut, nutmeg, banana (cv. Poovan), annual moringa (*Moringa oleifera* L.), elephant foot yam, and bitter gourd (*Momordica charantia* L.) resulted in greater coconut yield, higher net income, improved profitability, and a better benefit-cost ratio than monocropping of coconut (CPCRI, 2011).

Incorporating elephant foot yam into coconut-based cropping systems not only enhances overall coconut yield but also increases net returns, boosts employment opportunities, and improves the overall economic viability of coconut gardens (Anju et al., 2020). For an intercrop of elephant foot yam in coconut garden, half the quantity of FYM (12.5 t/ha) and one third of the NPK recommendation (26:30:33) will be sufficient, when green manuring *in situ* with cowpea is practiced (Ravindran and Kabeerathumna, 1991). Whereas, Pushpakumari and Sasidhar (1992) reported that for elephant foot yam intercropped in coconut garden the NPK dose can be reduced to 50%.

Minor tuber crops as intercrop: Pushpakumari and Sasidhar (1992) reported that for lesser yam (*Dioscorea esculenta*) intercropped in coconut garden, the NPK dose can be reduced to 75%. Productivity of arrowroot intercropped in coconut garden as influenced by spacing, mulching and N:K fertilization was investigated and validated in the southern humid tropics based on long-term on-station and on-farm experiments by ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Keralam, India. It was found that intercropping arrowroot at a spacing of 30 × 15 cm, mulching using locally available crop residues viz., green leaves, dried leaves and coconut fronds and application of FYM @ 10 t/ha and NPK @ 50:25:75 kg/ha resulted in higher rhizome yield (23.29 t/ha) and starch yield (4.37 t/ha) in arrowroot (Suja et al., 2003c; Suja and Nayar, 2005; Suja et al., 2006; 2021).



Coconut + cassava | Coconut + elephant foot yam | Coconut + white yam

Coconut + greater yam | Coconut + lesser yam | Coconut + dwarf white yam

Coconut + arrowroot | Coconut + tannia

Fig. 1. Coconut + tuber crops

Arecanut based intercropping systems

Arecanut palms spaced at 2.7 m × 2.7 m utilize 50% space and 50-75% sunlight (Nelliat, 1979) providing scope for intercropping. The productivity of root and tuber crops viz., cassava, elephant foot yam, greater yam, sweet potato, taro and arrowroot in association with arecanut palms was evaluated in a number of field experiments (Muralidharan and Nayar, 1979; Sannamarappa and Muralidharan, 1982; Nayar and Suja, 2004). Higher fresh tuber yield was obtained from elephant foot yam as intercrop in arecanut gardens. About 7000 elephant foot yam/yams could be accommodated at a spacing of 90 × 90 cm, leaving 1 m radius from the base of the palms. Care should be taken to manure both the main crop as well as the intercrop separately and adequately. However, higher biomass production was recorded in arrowroot indicating its ability to perform well under partially shaded conditions.

Banana based intercropping systems

Raising tuber crops like elephant foot yam, greater yam and white yam in the interspaces of *Nendran* and *Robusta* banana is productive and profitable, besides saving fertilizer inputs (Nayar and Suja, 1996; Nayar and Suja, 1998; Nayar and Suja, 2002) (Fig. 2). Studies conducted at ICAR-CTCRI (Nayar and Suja, 1996) indicated that in between two rows of *Nendran* banana spaced at 3.6 m × 1.8 m, three rows of the tuberous intercrops namely greater yam or elephant foot yam could be planted at a spacing of 90 × 90 cm to accommodate 8000 plants per ha. It was also found that in such a system the farmyard manure, N and P dose can be reduced to 50%. Further investigations carried out by Nayar et al. (2001) revealed that in *Robusta* banana + *Dioscorea* intercropping system about 6000 plants of *Dioscorea* can be accommodated in a hectare at a spacing of 90 × 90 cm, without sacrificing the banana plant population of 2300 plants per ha (2.4 × 1.8 m). Banana should be fertilized at the full recommended dose and for *Dioscorea* 2/3 recommended level would be sufficient. Yams can be either trailed to banana or using cassava stems.

Banana + yams & aroids

Banana + lesser yam

Banana + white yam

Banana + dwarf white yam

Banana + elephant foot yam

Fig. 2. Banana + tuber crops

Fruit/tree crops based intercropping systems

The productivity of root and tubers in association with other tree species viz., cashew, coffee, rubber, eucalyptus and *Leucaena* has also been investigated (Fig. 3). Initially intercropping of yams received little attention in cashew. But intercropping has become popular with the systematic establishment of large-scale cashew orchards. It is practiced during 4-5 years when there is sufficient space between crop rows with the main objective of deriving some income until cashew starts giving economic returns (Suja and Nedunchezhiyan, 2018). Depending on soil and climatic conditions and local situations, yam can be grown as intercrop.

Elephant foot yam was the most ideal for intercropping in robusta coffee, mango, sapota and litchi orchards (Nayar, 1976; AICRP, 2006; AICRP, 2010). Nayar (1976) identified elephant foot yam as a profitable intercrop in robusta coffee producing yield of 18 t/ha. In low land conditions of Kerala, intercrops like elephant foot yam *(Amorphophallus),* yams *(Dioscorea)* and tannia *(Xanthosoma)* were tried in banana cv. *Nendran*. Yams were found to be most promising and yams had no adverse effect on banana yield (Nayar and Mohankumar, 1989). Suma et al. (1990) reported that banana intercropped with cassava was most economical, followed by banana + elephant foot yam.

The performance of elephant foot yam, greater yam, white yam and tannia intercropped in rubber plantation as influenced by three levels of manuring was evaluated (Nayar and Suja, 2000). Among the tuber crops, higher productivity was recorded for elephant foot yam, followed by greater yam. In young rubber plantations, during the initial 3-4 years, elephant foot yam/yams could be intercropped. But manuring at the full dose should be done for both the crops. It is possible to accommodate about 6000 plants in 1 ha of rubber plantation, after leaving 1.5 m radius from the base of the rubber plants.

Ghosh et al. (1987) evaluated the productivity of cassava in association with tree species like eucalyptus and *Leucaena* and found that cassava yield was reduced to 80% under eucalyptus and 70% under *Leucaena* when compared to sole crop yield by third year. They attributed this loss in productivity mainly to competition from the tree species for nutrients and moisture in addition to shade effect.

In Papua New Guinea, sweet potato is cultivated from sea level to altitudes up to 2800 m. It is the dominant or co-dominant crop in various intercropping systems. Sweet potato is grown as an intercrop with coffee in the New Guinea high land. In New Calidonia, large rectangular beds of 1 m height are formed between coconut trees for intercropping sweet potato (Nedunchezhiyan et al., 2012b).

Intercropping elephant foot yam with banana and papaya resulted in 80-90% of the corm yield obtained under sole cropping conditions (Nedunchezhiyan et al., 2002). Importantly, the practice did not adversely affect key yield attributes of banana, such as bunch weight, number of hands per bunch, number of fingers per hand, or individual finger weight. Likewise, in papaya, both fruit number and fruit weight remained unaffected by the inclusion of elephant foot yam as an intercrop. These findings suggest that elephant foot yam does not compete significantly with the main crops for nutrients, provided fertilizers are applied to each crop based on the net sown or planted area. Instead, any residual nutrients in the intercropped area appear to be effectively utilized by banana and papaya.

Furthermore, the inclusion of elephant-foot yam as an intercrop enhanced economic returns, increasing net income by ₹ 21,100 per ha in banana and ₹ 20,200 per ha in papaya compared to their respective sole cropping systems (Nedunchezhiyan et al., 2002).

Elephant foot yam can be successfully grown as an intercrop with banana and vegetable cowpea under partial shade of coconut. Under such intercropping conditions, reduced fertilizer doses are adequate, and studies have shown that reduced quantities of recommended NPK is required for intercrops due to improved nutrient use efficiency and resource sharing (Byju et al., 2016; TNAU, 2020).

Elephant foot yam can be successfully and profitably intercropped with bael (*Aegle marmelos*). Elephant foot yam acts as an excellent shade-tolerant, high-value intercrop in young orchards, including bael, making full use of the wide spacing between trees in the initial years. Growing green manure crops in bael planted in degraded lands and *in situ* incorporation reduced manures and fertilizers requirements in such association.

Rubber + greater yam

Mango + tuber crops
(Source: AICRP, 2006)

Sapota + elephant foot yam
(Source: AICRP, 2010)

Mango + cassava (Source: AICRP, 2010)

Fig. 3. Other fruits/plantation crops + tuber crops

The socio-economic analysis of the integration indicated that tuber crops provided on an average additional yield (10-12 t/ha), generated added profit (₹1,00,000-1,25,000 per ha), employment opportunities (150-200 man days per ha) and enabled sustainable livelihoods (Table 4).

Table 4. Socio-economic analysis of tuber crops in association with plantation crops

Production system	Yield (t/ha)	Net returns (₹/ha)
Coconut + cassava	10-12	90000-100000
Yams as intercrop		
Coconut + yams	12-13	125000-150000
Banana + yams	17-18	150000-200000
Rubber + yams	10-12	75000-80000
Elephant foot yam as intercrop		
Coconut + elephant foot yam	14-16	200000-250000
Banana + elephant foot yam	16-17	250000-300000
Rubber + elephant foot yam	20-22	300000-400000
Arecanut + elephant foot yam	10-12	75000-80000
Tannia /Arrowroot as intercrop		
Coconut + tannia	6-7	100000-125000
Banana + tannia	5-6	90000-100000
Rubber + tannia	6-7	100000-125000
Coconut + arrowroot	15-20	300000-350000

Oil palm based intercropping systems

Intercropping in oil palm is widely practiced across regions. In West Africa, the origin of oil palm, it forms part of agroforestry systems, where palms are grown in polyculture with food and perennial crops (Khasanah et al., 2016). Growing concerns such as climate change, market fluctuations, and competition have renewed interest in intercropping to diversify income and optimize land use.

In Uganda, especially Kalangala near Lake Victoria, smallholders intercrop oil palm with crops like cassava for food and additional income. In Ghana, although plantations follow monocropping, smallholders intercrop food and cash crops during the first three years of palm establishment for socio-economic benefits (Sparnaaij, 1957; Norman, 1974; Nuertey, 2000). This practice has also become important due to food scarcity around major estates such as BOPP, TOPP, and GOPDC. In Malaysia, cassava is grown in double-row alley systems, enabling continuous intercropping with minimal impact on palm yield (Namanji et al., 2020). Similar practices are observed in Indonesia.

A study in southwest Cameroon reported that intercropping generated an average annual income of 705,000 FCFA (€1075) per hectare per household. Key intercrops included cassava (*Manihot esculenta*), taro (*Colocasia esculenta*), and yam (*Dioscorea* sp.), with yam contributing over 50% of total intercrop income (Nchanji et al., 2016).

Earlier findings in Nigeria showed that intercropping oil palm with yam, maize, cassava, and cocoyam during early growth stages did not adversely affect palm yield (Sparnaaij, 1957). Similar results were reported in Indonesia (Nuertey, 2000). In India, research at the Indian Institute of Oil Palm Research, Palode, Keralam, demonstrated that integrating shade-loving, multi-tier crops in mature plantations (>12 years) nearly doubled net income without reducing oil palm yield (Murugesan and Sunitha, 2018).

Andhra Pradesh, Telangana and Keralam are the leading states in oil palm production. Oil palm as a smallholder's crop under irrigation has completed it's one crop cycle of 30 years. Replanting of earliest planted oil palm plantations (started in 1991-92) has already begun, highlighting the need to enhance farmer income and optimize land use.

Cassava and other tuber crops are widely preferred and have strong market demand in these regions, making them suitable intercrops to support farmers during the initial stages. In practice, farmers have already integrated elephant foot yam in Andhra Pradesh and arrowroot in Odisha as intercrops in established oil palm gardens (Ramachandrudu et al., 2013).

Cultivation of tropical tuber crops like cassava, yams, edible aroids and arrowroot in the interspaces of oil palms, is certainly a way of enhancing farm-level income and enabling employment opportunities. Since tuber crops are suited to the same ecological conditions as plantation crops, food production can be significantly increased by including yams and aroids in the current perennial tree-based cropping systems (Byju et al., 2023).

The North-Eastern region of India, comprising Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, is emerging as a new zone for oil palm cultivation. The region offers strong potential for tuber crops such as taro, cassava, yam, and elephant foot yam due to its diverse agroclimatic conditions, varied soils, and high but uneven rainfall.

Tuber crops already play a key role in food and nutritional security, particularly among tribal communities. Crops like cassava, taro, and yam are commonly grown in jhum (shifting cultivation) systems, while taro is also widely cultivated in both hill and plain areas of Assam and Tripura. Species such as *Dioscorea alata* and *Dioscorea esculenta* are typically grown in backyards or collected from forests. Likewise, *Colocasia*, *Xanthosoma*, and *Amorphophallus* are commonly found in the wild and in household gardens.

Given this existing familiarity and adaptability, integrating tuber crops as intercrops in oil palm plantations across the region is both feasible and sustainable.

Intercropping in the oil palm plantation can be done mainly in 3 ways as given below (Table 5).

Table 5. Intercropping in oil palm

Age of the oil palm	Intercrops	Spacing	Reference
Young plantation (up to 5 years)	Cassava	9 m × 9 m × 9 m triangular spacing of palms with inter row planting at 0.7 m × 1m (6 rows) spacing at least 2 m away from the palm	Namanji et al. (2020)
Mature plantation (>5 years)	Yams, Taro	9 m × 9 m × 9 m triangular spacing of palms with inter row planting at 1m × 1m × 1m spacing and rows of yams at least 2 m away from the palm	Namanji et al. (2020)
Double-row alley system	Yams, Taro and Cassava	Intercropping in 15 m wide alleys between each double row of oil palm planted in 6 m × 6 m × 6 m spacing	Suboh et al. (2009) Slingerland et al. (2019) and Namanji et al. (2020)

4. Tuber Crops Based Intercropping Systems with Annuals

Tuber crops such as cassava, sweet potato, yams, elephant foot yam, taro and tannia play an important role in food security and farming systems in tropical regions. Intercropping these crops with annuals is an efficient practice that helps maximize land use and productivity. In such systems, short-duration annual crops like pulses, cereals, and vegetables are grown along with tuber crops during their early growth stages. This approach not only provides additional income but also improves soil fertility and reduces weed growth. By making better use of available resources like sunlight, water, and nutrients, tuber crop-based intercropping systems contribute to sustainable and resilient agriculture.

Intercropping in cassava

In India, field trials on intercropping systems with cassava have been initiated since 1968 mainly at ICAR-CTCRI and very useful recommendations have been obtained. Later, on farm performance of certain intercrops like groundnut and cowpea confirmed the acceptability of such systems (Table 6). Several grain legumes like cowpea (*Vigna unguiculata),* mungbean *(Phaseolus mungo),* soybean (*Glycine* max), groundnut *(Arachis hypogaea)* and pigeon pea (*Cajanus cajan)* have been tried as intercrops for the main season (May-June planting) crop of Keralam State (Ghosh, 1994).

Table 6. Performance of groundnut and cowpea as intercrops in cassava

Intercrops	Grain yield (kg/ha)	Cassava tuber yield (t/ha)			Source
		Mono culture	Inter-cropped	Yield reduction (%)	
Groundnut	1380	31.3	20.0	36.1	Prabhakar et al.(1984) Muthukrishnan and Thamburaj (1978) Mohankumar and Hrishi (1978) CTCRI (1983)
	620	24.9	19.7	20.9	
	1555	21.9	18.9		
	1253	26.6	21.3	19.9	
Cowpea	1050	31.3	25.2		Prabhakar et al.(1984) Muthukrishnan and Thamburaj (1978), CTCRI (1983)
	2030	24.9	16.6	33.3	
	803	26.5	23.3		

Source: Ghosh (1994)

Vegetable crops like cucumber (*Cucumis sativus),* French bean *(Phaseolus vulgaris),* cowpea (*Vigna sinensis)* and okra *(Abelmoschus esculenta)* were tried as intercrops in cassava. The results showed that French bean (cv. Contender, Premier) was found to be the most economical one. Green pod yield of 1500 kg/ha in three to four pickings during 45 to 70 days after planting was recorded. Short duration medicinal plant periwinkle (*Vinca rosea)* when intercropped with cassava was found to yield about 245 kg of dry roots and 415 kg of dry shoots per hectare by five months-time. Mohankumar et al. (1980) observed that profits obtained from intercrops like French bean and groundnut were similar. Prabhakar and Pillai (1984) worked out the economics of intercropping (Table 7) cassava for Keralam conditions and observed that cassava + groundnut, cassava + French bean and cassava + periwinkle are profitable.

Table 7. Economics of intercropping in cassava

Crop combination	Yield of cassava (t/ha)	Yield of intercrop (kg/ha)	Income from cassava (₹/ha)	Income from intercrop (₹/ha)	Cost of cultivation (₹/ha)	Net income (₹/ha)
Cassava + French bean	24.04	1503	9616	3006	7000	5622 (24.1)
Cassava + groundnut	21.29	1253	8516	3759	7000	5275 16.4)
Cassava + cowpea	23.32	803	9328	2810	6850	5288 (16.7)
Cassava + pigeon pea	19.06	704	7624	3520	6500	4644 (2.5)
Cassava + maize	22.12	1242	8848	2484	6500	4832 (6.6)
Cassava + periwinkle	22.63	415	9052	3072	6700	5424 (19.7)
Cassava alone (control)	26.58		10632		6100	4532

Source: Prabhakaran and Pillai (1984); Figures in parantheses indicate per cent increase over control (sole cassava)

Table 8. Management practices for intercrops in cassava

Name of the crop	Varieties	Duration (days)	Spacing (cm)	No. of rows	Seed rate (kg/ha)	NPK (kg/ha)	Yield (kg/ha)
Groundnut	TMV-2 TMV-7 Pollachi-2	100	30 x 20	2	40-45 (kernel)	10:20:20	1200 (dry pod)
French bean	Contender	70	30 x 20	2	40	20:30:40	2000
Cowpea (grain)	S-488	90	30 x 15	2	20	10:15:10	800
Cowpea (vegetable)	B-61 (Arka Garima) Anaswara	65	90 x 20	1	8	10:15:10	3000

Source: Ravindran et al. (2013); Suja et al. (2023)

In south India, cassava intercropping with legumes (groundnut, cowpea, black gram) and vegetables (French bean, onion, coriander, okra) was found feasible (Prabhakar et al., 1983; Mohankumar and Ravindran, 1990) (Fig. 4). Management practices to be followed are given in Table 8. Tuber crops like lesser yam, elephant foot yam etc. can also be grown in association with cassava.

Intercropping in inter rows of cassava (additive series) with sesame (*Sesamum indicum*) and sunflower (*Helianthus annus* L.), cowpea, vegetable cowpea, peanut, soybean, mungbean (*Vigna radiata* L.), chickpea (*Cicer arietinum* L.), blackgram (*Vigna mungo* L.) and okra significantly reduced storage root yield of cassava and its components such as storage root number and weight per plant. The reduction of cassava storage root yield was 24-40%, when sunflower was intercropped and 14-31% when sesame was intercropped, compared to sole cassava (Adekunle et al., 2014). Intercropping vegetable cowpea, mungbean, chickpea and egusi melon (*Cucumer opsismannii* L.) reduced storage root yield of cassava by 8.4 to 39.0% (Mbah, 2018), 50% (Hidoto and Loha, 2013), 29% (Ogola et al., 2013) and 30% (Ijoyah and Jimba, 2012a), respectively.

Cassava + cowpea


Cassava + groundnut

Fig. 4. Intercropping systems in cassava

Intercropping of pulses, oilseeds, vegetables in cassava had higher system productivity and land-use efficiency. The land equivalent ratios (LER) of cassava + sesame system varied between 1.2 and 1.5, cassava + sunflower system between 1.1 and 1.4 (Adekunle et al., 2014). Cassava + vegetable cowpea system had greater LERs (1.24-1.5) (Mbah, 2018). The LER for cassava + peanut was 41% higher than sole cassava, evincing that the integration of peanut with cassava is considerably productive (Ogola et al., 2013). In cassava + mungbean intercropping system, the high LER (1.6) indicates that the system was highly productive (Hidoto and Loha, 2013). The LER for cassava + chickpea was 46% higher than sole cassava, indicating that the integration of chickpea with cassava was considerably productive (Ogola et al., 2013). The LER value of 1.8 for the intercropping system of cassava + sweet potato indicated that the system was highly productive and that the 80% land saved could be used for cultivation of other crops (Ijoyah and Aghimien, 2012b).

Intercrops in cassava suppresses weed growth and thereby the weed biomass production is drastically reduced. Integration of pigeonpea with cassava significantly reduced the weed density by 26.5% relative to the sole-cassava planting (132 weeds/m^2), whereas the weed dry biomass was reduced by 15.6% in the cassava + pigeonpea system relative to sole cassava (76 g/m^2) (Ravi et al., 2021). The lower weed biomass under the cassava + pigeonpea system relative to sole cassava could be adduced to greater shading effects on weeds by cassava and pigeonpea than by cassava alone. The weed control efficiency of cassava + vegetable cowpea system was 44.5%, whereas in sole crop of cassava it was 14.0% (Ravi et al., 2021).

Cassava-based intercropping systems could reduce mealybug populations by 37% (Delaquis et al., 2018). A survey by Njukwe et al. (2011) on pests and diseases in cassava in Rwanda, where cassava green mite (*Mononychellus tanajoa* L.) and cassava whitefly (*Bemisia tabaci* L.) (vector of cassava mosaic virus), were the most abundant pests, revealed that intercropping was associated with lower pest population, disease incidence and severity. Intercropping bean, maize, sweet potato and sorghum, with cassava could reduce cassava mosaic disease incidence to 29% relative to a sole crop of cassava (40%), whereas cassava green mite incidence was reduced to 41% relative to sole crop of cassava (48%) (Njukwe et al., 2011).

Intercropping in sweet potato

Sweet potato, a short-duration (100-120 days) crop can be grown during rainy season in hilly and plateau regions and post-rainy season in plains with supplemental irrigation. It can be intercropped with cereals and pulses (Nedunchezhiyan et al., 2012b). Nedunchezhiyan et al. (2006a) also recommended sweet potato as an intercrop in upland rice (*Oryza sativa* L.) for a contingent plan against the crop failure as well as for soil and water conservation. Njoku et al. (2007) reported that intercropping okra (*Abelmoschus esculentus* L.) as intercrop in sweet potato did not affect the sweet potato root yield.

Sweet potato and red gram strip intercropping (1:1) performs well in upland ecosystems (Nedunchezhiyan, 2011). Intercropping in sweet potato markedly influences yield attributes, system productivity, and pest incidence. Yield components such as number of storage roots per plant, root length, and root diameter were significantly higher in border rows than inner rows, indicating strong border effects; correspondingly, the aggressivity index was also higher at borders and declined towards the middle rows (Nedunchezhiyan, 2011).

Crop compatibility affected performance within intercropping systems. Maize, due to its strong early competition, resulted in only a 5.4% increase in sweet potato root yield over sole cropping (Nedunchezhiyan et al., 2010a). In contrast, pigeonpea, being a long-duration crop, utilized residual resources more effectively after sweet potato harvest and exhibited higher aggressivity in the system (Nedunchezhiyan et al., 2011a). Overall, intercropping enhanced sweet potato productivity, with yield gains of up to 27.7% compared to sole cropping.

Intercropping also improved land-use efficiency and economic returns. Strip cropping of sweet potato (ridge and furrow) with pigeonpea (flat-bed) in a 1.8 m (3:3 row) arrangement under rainfed upland conditions of Odisha (Fig. 5) resulted in higher storage root equivalent yield (13.53 t/ha), net returns (₹ 28075/ha), and benefit:cost ratio (3.24) (Table 9) (Nedunchezhiyan et al., 2010a).

Fig. 5. Sweet potato + pigeonpea (3:3) strip intercropping

Table 9. Storage root equivalent yield and economics of sweet potato-based strip intercropping systems (Pooled data of 3 years)

Cropping system	Storage root yield (kg/ha)	Seed yield (kg/ha)	Storage root equivalent yield (t/ha)	LER	Net return (₹/ha)
Sole cropping					
Sweet potato	13.37	-	13.37	-	21822
Rice	-	2532	4.22	-	4010
Ragi	-	1778	2.96	-	990
Maize	-	2395	3.99	-	3335
Pigeonpea	-	1877	7.51	-	15088
Strip intercropping					
Sweet potato + rice	7.94	1392	10.26	1.14	16968
Sweet potato + ragi	8.22	931	9.75	1.14	16339
Sweet potato + maize	7.04	1309	9.22	1.08	14307
Sweet potato + pigeonpea	8.54	1249	13.53	1.31	28075
CD (0.05)	-	-	0.403	-	-

Source: Nedunchezhiyan (2011)

Furthermore, intercropping systems with crops such as rice, finger millet (*Eleusine coracana* L.), maize, and pigeonpea required 8-31% less land to achieve yields comparable to sole cropping, while also providing diversified outputs and supplementary income (Nedunchezhiyan, 2011).

In addition, strip intercropping reduced sweet potato weevil (*Cylas formicarius* L.) damage, with the lowest incidence observed in sweet potato + maize, followed by sweet potato + pigeonpea systems (Nedunchezhiyan et al., 2010b) (Table 10).

Table 10. Sweet potato weevil infestation in the various intercropping treatments

Treatment	Number of weevil infested vines/m^2						Weevil infested roots (%)		
	80 DAP			120 DAP					
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Sweet potato	0.86	0.74	0.92	1.16	0.98	1.02	9.3	8.9	9.1
Rice	-	-	-	-	-	-	-	-	-
Ragi	-	-	-	-	-	-	-	-	-
Maize	-	-	-	-	-	-	-	-	-
Red gram	-	-	-	-	-	-	-	-	-
Sweet potato + rice	0.62	0.59	0.64	1.08	0.84	0.90	7.0	7.4	7.2
Sweet potato + ragi	0.58	0.64	0.57	0.96	0.80	0.86	7.2	7.0	7.4
Sweet potato + maize	0.20	0.22	0.18	0.74	0.68	0.65	6.2	6.0	5.9
Sweet potato + red gram	0.74	0.65	0.68	0.86	0.82	0.80	6.4	6.6	6.8

Source: Nedunchezhiyan et al. (2010b)

Intercropping in yams

Influence of intercrops on growth and yield of greater yam in different planting systems was studied in detail by Nedunchezhiyan and Byju (2006). Intercropping of maize, sorghum and redgram/pigeonpea increased the tuber yield of greater yam apart from additional yield from intercrops compared to sole cropping of greater yam (Nedunchezhiyan, 2007). The reduction in anthracnose (*Colletotrichum gloeosporioides*) incidence in greater yam was 55.4-59.7%, when these crops were included as intercrop (Nedunchezhiyan et al., 2006b). Production efficiency of yam + maize/sorghum/pigeonpea was higher than sole yam. Intercropping of pigeonpea had system advantage of 31.4% over sole yam crop (Nedunchezhiyan and Byju, 2006). Similarly, energy output:input ratio and energy use efficiency were higher in yam + maize/sorghum/pigeonpea than sole yam (Nedunchezhiyan, 2007).

Maize was identified as a suitable companion crop in greater yam (Fig. 5). Greater yam + maize system (normal row planting) reduces anthracnose incidence by 59.7%, increases yam yield by 26.3% (17.30 t/ha), produces maize yield of 1425 kg/ha, tuber equivalent yield of 18.73 t/ha (+36.7% than sole greater yam), production efficiency of 89.20 kg/ha/day, additional net return of ₹ 22,055/ha (Fig. 6) (Nedunchezhiyan et al., 2006b; Nedunchezhiyan et al., 2008c) (Table 11).


Fig. 6. Greater yam + maize intercropping system

Table 11. Effect of intercrops and planting pattern on productivity of greater yam based intercropping systems

Treatment	Tuber yield (g/plant)	Tuber yield (t/ha)	Intercrop yield (kg/ha)	Tuber equivalent yield (t/ha)	Land equivalent ratio	Production efficiency (kg/ha/day)
T1: Greater yam (normal row planting) + maize (*Zea mays* L.)	1540	17.30	1425	18.73	1.37	89.20
T2: Greater yam (normal row planting) + sorghum (*Sorghum bicolour* L.)	1400	16.00	1019	17.02	1.24	81.00
T3: Greater yam (normal row planting) + red gram (*Cajanus cajan* L. Millsp)	1470	16.20	900	18.00	1.31	85.70
T4: Greater yam (paired row planting) + maize	1500	16.80	1384	18.18	1.33	86.60
T5: Greater yam (paired row planting) + sorghum	1410	15.60	983	16.58	1.21	79.00
T6: Greater yam (paired row planting) + red gram	1440	15.60	839	17.28	1.26	82.30
T7: Greater yam (skipped row planting) + maize	1660	9.10	1538	10.64	0.78	50.70
T8: Greater yam (skipped row planting) + sorghum	1510	8.40	1084	9.48	0.69	45.20
T9: Greater yam (skipped row planting) + red gram	1600	8.60	965	10.53	0.77	50.10
T10: Greater yam sole crop (control)	1260	13.70	-	13.70	1.00	65.20
CD (0.05)	105	1.40	-	-	-	2.60

Source: Nedunchezhiyan et al. (2008c)

Input management for greater yam + maize intercropping is very vital to achieve higher yields. In greater yam + maize intercropping system a fertilizer dose of N:P_2O_5:K_2O @ 100:75:100 kg/ha (125% recommended dose of fertilizer of greater yam) along with mulching (2 t/ha dried farm waste) was recommended for Bhubaneswar, Odisha conditions (Nedunchezhiyan, 2010; Nedunchezhiyan et al., 2010c).

Nedunchezhiyan (2010) reported that in greater yam + maize intercropping system, higher total productivity (23.0 t/ha), productivity efficiency (109.5 kg/ha/day) and net return (₹ 55,700/ha) was obtained with the application of NPK @ 120:39.3:100 kg/ha along with mulching (2 t/ha). Combined application of plant residues with fertilizer improved soil organic C, total N, exchangeable Ca and Mg compared with application of NPK fertilizers alone. Incorporation of residues with reduced NPK fertilizer application may be a sustainable soil fertility management option for continuous yam production (Hgaza et al., 2012). Manure application did not have a significant effect on yam total biomass production nor on tuber yield when applied on fields after fallow. Crop residue application had a positive significant effect on yam tuber and total biomass production when applied after cotton and maize and with adequate amount of rainfall and distribution.

Fig. 7. Experimental view of dwarf white yam + pulse intercropping systems and tuber yield under intercropping with green gram at the reduced nutrient level

Non-trailing genotypes of white yam (*Dioscorea rotundata*), lesser known, are long-duration and widely spaced with scope for intercropping. Field experiments were conducted over two seasons at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Keralam, to assess the feasibility of intercropping dwarf white yam var. Sree Dhanya with three pulse crops [green gram (var. Co-Gg-7), black gram (var. Co-6), and soybean (var. JS-95-60)] under two nutrient levels (ICAR-CTCRI, 2018; 2019; 2020) (Fig. 7). Averaging over two years, yield of dwarf white yam under intercropping (23.07 t/ha) was comparable to sole cropping (22.90 t/ha), with a slight increase. Dwarf white yam var. Sree Dhanya intercropped with green gram at the reduced nutrient level was productive (tuber yield, 26.78 t/ha; tuber equivalent yield, 28.26 t/ha; production efficiency, 104.66 kg/ha/day, profitable (net returns, ₹ 8,09,095 per ha; B:C ratio, 3.52) and better than sole dwarf white yam (added profit of ₹ 1,83,842 per ha over sole crop) (Table 12). Besides, there was nutrient saving of half FYM and N and all P to dwarf white yam. The intercropping systems did not significantly impact the soil chemical properties underscoring the scope of intercropping pulses in dwarf white yam as a sustainable practice. These findings underscore that intercropping dwarf white yam with pulses, particularly under reduced nutrient inputs, enhances yield, economic returns and resource-use efficiency, providing a viable strategy for sustainable agricultural intensification.

Table 12. System productivity and profitability as affected by intercropping systems involving dwarf white yam and nutrient levels (average of two years)

Systems	Yield		Tuber equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Net returns	Added profit	B:C ratio
	White yam (t/ha)	Pulse (kg/ha)			(₹/ha)		
White yam + GG (F1)	21.93	438.98	23.58	87.32	615340	-9913	2.88
White yam + GG (F2)	26.78	395.34	28.26	104.66	809095	183842	3.52
White yam + BG (F1)	19.57	369.26	20.91	77.45	519068	-106185	2.64
White yam + BG (F2)	26.10	364.83	27.43	101.57	786037	160783	3.53
White yam + SB (F1)	20.55	864.84	24.87	92.10	689907	64653	3.26
White yam + SB (F2)	23.52	826.76	27.65	102.40	807317	182064	3.70
White yam (sole)	22.90		22.90	84.81	625253		3.15

GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full dose of FYM & N, no P, full K (FYM @ 10 t/ha; NPK @100:0:100 kg/ha); F_2-Half dose of FYM & N, no P, full K (FYM @ 5 t/ha; NPK @ 50:0:100 kg/ha)

Intercropping in elephant foot yam

Growing intercrops in elephant foot yam is a wide spread practice. A comparatively wider spacing of 90 cm × 90 cm has been identified as optimum for planting elephant foot yam. Further, it takes long time to give sprouts and it takes nearly 90 days to cover the ground surface. Hence, during the earlier stages of crop growth, enough sunlight and interspace are available and there is a possibility of growing bushy, short duration vegetable intercrops like onion, French bean, cowpea, cauliflower etc. and also short duration pulses like greengram, blackgram, cowpea (Nedunchezhiyan and Byju, 2005).

Different intercrops were tried in elephant foot yam viz., sweet potato, green gram, black gram and vegetable cowpea, in different planting patterns (normal row, paired row and skipped row planting) at ICAR-CTCRI Regional Station, Bhubaneswar, Odisha (Nedunchezhiyan and Byju, 2005). All the intercrops, except sweet potato, resulted in higher net income over sole cropping of elephant foot yam, irrespective of planting patterns (Table 13). Elephant foot yam (normal row planting) + green gram (Fig. 8), elephant foot yam (normal row planting) + black gram and elephant foot yam (normal row planting) + vegetable cowpea resulted in additional net income of ₹ 11,665, 11,090 and ₹ 9,925 respectively over sole crop of elephant foot yam. Similar trend was observed in paired row planting. Increase in net income over sole crop of elephant foot yam was not appreciable in skipped row planting. These crops offer little competition to elephant foot yam. After harvesting of green gram or black gram, the haulms could be re-used as mulch or incorporated. Because of mulching at later stage, higher yield was obtained in elephant foot yam compared to sole crop at Bhubaneswar, Odisha. Nedunchezhiyan et al. (2008d) reported mulching of elephant foot yam + green gram immediately after planting/sowing increased elephant foot yam corm yield by 21.6% over no mulching. The net additional income of ₹ 15,000/ha was obtained in such cropping.

Green gram intercropped in elephant foot yam

Mulching with green gram residues after harvest in elephant foot yam + green gram intercropping system

Fig. 8. Elephant foot yam + green gram intercropping system at Bhubaneswar

Table 13. Yield and economics of elephant foot yam based cropping system (Pooled data of two years)

Notation	Treatments	Elephant foot yam yield (t/ha)	Intercrop yield (kg/ha)	Corm equivalent yield (t/ha)	Net return (₹/ha)	Increase/decrease in net return over sole cropping of elephant foot yam (₹/ha)
T_1	Elephant foot yam sole crop	14.42	-	14.42	20930	-
T_2	Elephant foot yam (normal row planting) + sweet potato	11.93	4104	14.39	14740	- 6190
T_3	Elephant foot yam (normal row planting) + green gram	15.95	499	16.94	32595	11665
T_4	Elephant foot yam (normal row planting) + black gram	15.52	659	16.84	32020	11090
T_5	Elephant foot yam (normal row planting) + vegetable cowpea	14.73	3163	16.63	30855	9925
T_6	Elephant foot yam (paired row planting) + sweet potato	12.42	3924	14.77	16775	4155
T_7	Elephant foot yam (paired row planting) + green gram	15.66	468	16.60	30915	9985
T_8	Elephant foot yam (paired row planting) + black gram	15.23	622	16.48	30265	9335
T_9	Elephant foot yam (paired row planting) + vegetable cowpea	14.62	2745	16.27	29105	8175
T_{10}	Elephant foot yam (skipped row planting) + sweet potato	7.14	4748	9.99	17655	- 3275
T_{11}	Elephant foot yam (skipped row planting) + green gram	8.46	538	9.53	22020	1090
T_{12}	Elephant foot yam (skipped row planting) + black gram	8.23	694	9.62	22410	1480
T_{13}	Elephant foot yam (skipped row planting) + vegetable cowpea	8.21	3259	10.17	25035	4105
	CD (0.05)	1.21	256	1.11	1562	-

Source: Nedunchezhiyan and Byju (2005)

In Wayanad (North Keralam), elephant foot yam is normaly planted in November at 120 cm x 120 cm spacing. During initial stage, farmers grow cucumber or amaranthus as intercrop in the wider spaces of elephant foot yam and harvest within 60-75 days after sowing.

In Tamil Nadu (India), vegetable cowpea (cv. CO-2), cluster bean (*Cyamopsis tetragonoloba* L.) (cv. Pusa Navbahar), okra (cv. Parbhani Kranti), aggregatum onion (*Allium cepa* var. aggregatum L.) (cv. CO-4) and amaranthus (cv. CO-3) were grown as intercrops in elephant foot yam. The results indicated that intercropping elephant foot yam with vegetable cowpea yielded higher elephant foot yam corm yield (49.3 t/ha) than elephant foot yam sole cropping. The highest economic returns were obtained when elephant foot yam was intercropped with vegetable cowpea. Similar result was reported under West Bengal conditions also (Jata et al., 2019).

In simultaneously planted/sown elephant foot yam + green gram intercropping system, application of mulch resulted in significant effect on corm yield. Nedunchezhiyan et al. (2008d) reported mulching of elephant foot yam + green gram immediately after planting/sowing increased elephant foot yam corm yield by 21.6% over no mulching in intercropping situation. However, such effect was not noticed in green gram. Productivity efficiency, production efficiency, net return and benefit:cost ratio were higher due to mulching than no mulching of elephant foot yam + green gram intercropping system (Nedunchezhiyan et al., 2008d). Weeds often germinate and grow earlier than elephant foot yam, which can be suppressed by growing intercrops (Nedunchezhiyan et al., 2021a).

Elephant foot yam + ginger (1:2) | Elephant foot yam + ginger (1:1) | Elephant foot yam + turmeric (1:1)

Fig. 9. Elephant foot yam + spices intercropping system at Bhubaneswar

Intercropping studies to assess the production potential of intercropping spices (ginger and turmeric) in elephant foot yam conducted in eastern India indicated that introduction of intercrops and increasing their population significantly increased pseudostem height and decreased pseudostem girth, canopy spread and production of leaflets in elephant foot yam (Nedunchezhiyan, 2014). Incidence of collar rot decreased in intercropping systems and minimum of 6.0% was observed in elephant foot yam + turmeric (1:2) intercropping (Fig. 9).

The land equivalent ratio (LER) of all the intercropping systems was more than one, which indicated that they were biologically more efficient (Table 14). The intercropping systems showed superiority over sole cropping in total productivity and starch content, and reduction in calcium oxalate content (Table 15). The highest corm equivalent yield (39.6 t/ha), gross (₹ 3,96,000 per ha) and net returns (₹ 2,33,000 per ha) and benefit:cost ratio (2.43) were noticed in elephant foot yam + ginger (1:2) (Table 15).

Table 14. Productivity of elephant foot yam + spices intercropping (Pooled data of 3 years)

Treatments	Elephant foot yam			Intercrops			Corm equivalent yield (t/ha)	LER
	Collar rot incidence (%)	Corm yield (g/plant)	Corm yield (t/ha)	No. of mother rhizomes	Rhizome yield/ plant (g)	Rhizome yield (t/ha)		
Elephant foot yam (sole crop)	9.6	3000	36.0	-	-	-	36.0	1.00
Ginger (sole crop)	-	-	-	2.3	68.1	10.2	35.8	1.00
Turmeric (sole crop)	-	-	-	2.6	83.4	13.1	19.7	1.00
Elephant foot yam + ginger (1:1 additive series)	9.1	2830	34.0	2.7	90.2	1.1	38.1	1.06
Elephant foot yam + ginger (1:2 additive series)	8.8	2740	32.9	2.5	77.8	1.9	39.6	1.10
Elephant foot yam + turmeric (1:1 additive series)	7.3	2775	33.3	3.2	180.3	2.2	36.6	1.02
Elephant foot yam + turmeric (1:2 additive series)	6.0	2560	30.8	2.8	143.2	3.3	35.8	1.00
CD (0.05)	1.1	262	2.6	0.2	7.6	0.6	3.4	-

Source: Nedunchezhiyan (2014)

Under humid tropical conditions of south India at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Keralam, Suja et al. (2025a) reported that yield of elephant foot yam under intercropping with pulse crops (green gram, black gram, soybean) (32.82 t/ha) was comparable to sole cropping (35.90 t/ha), with a slight decrease of 8.58% (Fig. 10 & Fig. 11). Among elephant foot yam varieties, Gajendra was the most compatible for intercropping situation. Notably, the combination of elephant foot yam var. Gajendra + soybean var. JS-95-60 under full nutrient level resulted in higher corm yield (66.40 t/ha), corm equivalent yield (66.77 t/ha), production efficiency (247.30 kg/ha/day), equivalent energy (239.91 × 103 MJ/ha), net income (₹ 10, 09, 856 per ha), B:C ratio (3.20) and added profit of ₹ 2,33,164 per ha over sole cropping of elephant foot yam var. Gajendra (46.48 t/ha, 172.45 kg/ha/day, 167.33 × 10^3 MJ/ha). These intercropping systems did not adversely affect the soil chemical properties or the biochemical constituents of the corms, underscoring the viability of intercropping elephant foot yam with pulses as a sustainable practice.

Table 15. Biochemical composition of elephant foot yam and economics of elephant foot yam + spices intercropping (Pooled data of 3 years)

Treatments	Biochemical composition of elephant foot yam				Economics of elephant foot yam + spices system			
	Dry matter (%)	Starch (% on fresh weight basis)	Total sugars (% on fresh weight basis)	Calcium oxalate value (mg/100 g on fresh weight basis)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Elephant foot yam (sole crop)	22.00	15.40	1.35	86	150000	360000	210000	2.40
Ginger (sole crop)	-	-	-	-	202000	358000	156000	1.77
Turmeric (sole crop)	-	-	-	-	120000	197000	77000	1.64
Elephant foot yam + ginger (1:1 additive series)	21.90	16.30	1.33	84	158000	381000	223000	2.41
Elephant foot yam + ginger (1:2 additive series)	21.50	17.00	1.34	80	163000	396000	233000	2.43
Elephant foot yam + turmeric (1:1 additive series)	21.80	16.20	1.36	79	155000	366000	211000	2.36
Elephant foot yam + turmeric (1:2 additive series)	21.60	17.20	1.34	75	159000	358000	199000	2.25
CD (0.05)	NS	1.30	NS	4				

Source: Nedunchezhiyan (2014)

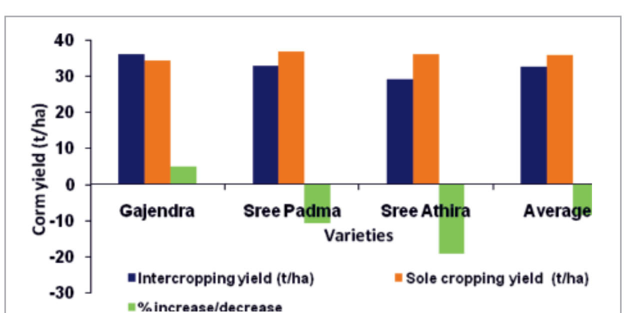


Fig. 10. Corm yield: Intercropping vs sole cropping in elephant foot yam
Source: Suja et al. (2025a)

Elephant foot yam + black gram

Elephant foot yam + green gram

Elephant foot yam after harvest of intercrops

Corm yield: Gajendra

Corm yield: Sree Padma

Fig. 11. Elephant foot yam + pulse crops

As depicted in Fig. 12 and Fig. 13, the comparative analysis indicates that intercropping did not significantly alter the soil chemical properties. The parameters evaluated included soil pH, organic C content, electrical conductivity, available N, P and K, as well as exchangeable Ca. The stability of these parameters across different cropping systems suggests that intercropping elephant foot yam with pulses does not detrimentally affect the fertility and health of the soil. This finding reinforces the viability of intercropping as a sustainable agricultural practice that maintains soil quality (Suja et al., 2025a).

In evaluating the biochemical attributes of elephant foot yam corms, the study scrutinized the potential effects of intercropping versus sole cropping systems. As shown in Table 16, intercropping did not significantly alter the corm biochemical composition.

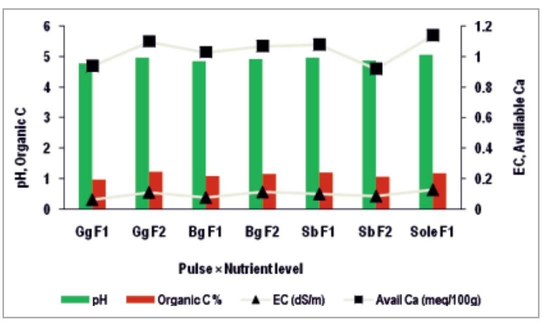


Fig.12. Effect of pulses × nutrient levels on pH, organic C, EC and exchangeable Ca of soil

Source: Suja et al., 2025a

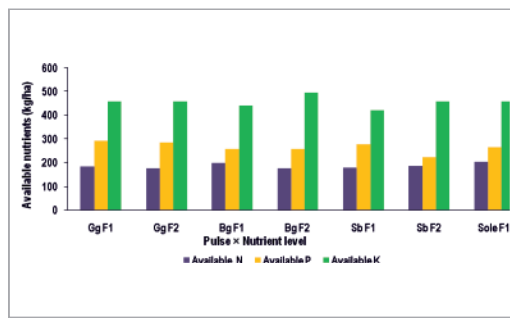


Fig.13. Effect of pulses × nutrient levels on available N, P and K status of soil

Source: Suja et al., 2025a

Intercropping in taro

In upland ecosystem, taro is grown as sole crop as well as intercropped with maize. In lowland ecosystem, it is grown as sole crop. A field experiment was conducted at the Regional Station of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India for three consecutive years (2018-2000) on alfisols under rainfed conditions to study intercropping of grain crops in taro. The experiment was laid out in a randomized block design with three replications. The experiment consisted of seven treatments, T_1-sole taro, T_2-sole maize, T_3-sole pigeon pea, T_4-taro + maize (5:1), T_5-taro + maize (5:2), T_6-taro + pigeon pea (5:1) and T_7-taro + pigeon pea (5:2) (Fig. 14). All the crops in intercropping were planted at 45 × 30 cm spacing under replacement series. Sole taro was planted at 45 × 30 cm spacing, whereas sole maize and pigeon pea at 60 × 30 cm spacing. The cormel equivalent yield of taro under sole cropping (18.59 t/ha) was higher and comparable to taro + maize (5:1) (16.90 t/ha) and taro + pigeonpea (5:1) (16.64 t/ha) intercropping systems (Table 17).

Table 16. Effect of treatments on corm biochemical composition under elephant foot yam - pulse intercropping system

Treatments	Dry matter %	Starch FW %	Sugar FW (%)	Crude protein FW (%)	Ash DW (%)	Crude fibre DW (%)
Gajendra GgF1	23.27	16.92	0.42	4.55	4.37	1.25
Gajendra GgF2	21.35	15.63	0.38	4.42	4.00	1.40
Gajendra BgF1	27.70	16.35	0.40	4.54	5.40	1.35
Gajendra BgF2	24.07	15.64	0.40	3.21	4.28	1.35
Gajendra SbF1	26.05	17.98	0.40	4.34	4.33	1.55
Gajendra SbF2	24.21	14.60	0.35	4.06	4.61	1.50
Sree Padma GgF1	21.43	15.71	0.40	3.77	3.64	1.45
Sree Padma GgF2	24.24	18.45	0.41	4.09	4.54	1.60
Sree Padma BgF1	24.04	17.68	0.43	3.63	4.39	1.41
Sree Padma BgF2	19.00	14.50	0.36	3.33	5.18	1.71
Sree Padma SbF1	21.24	14.77	0.37	3.62	4.88	1.47
Sree Padma SbF2	22.67	17.41	0.39	3.64	4.42	1.45
Sree Athira GgF1	18.07	14.08	0.32	4.36	5.07	1.93
Sree Athira GgF2	22.76	15.56	0.39	4.67	4.21	1.80
Sree Athira BgF1	24.03	17.80	0.45	4.38	4.42	1.47
Sree Athira BgF2	23.46	15.73	0.40	3.81	4.25	1.45
Sree Athira SbF1	28.40	17.54	0.45	4.56	3.52	1.45
Sree Athira SbF2	21.91	13.12	0.32	3.43	5.07	1.40
Sole Gajendra	25.07	17.47	0.42	4.35	4.22	1.45
Sole Sree Padma	21.53	15.05	0.37	4.01	4.25	1.60
Sole Sree Athira	22.32	16.39	0.42	3.81	4.16	1.80
CD (0.05)	NS	NS	NS	NS	NS	NS

Gg-Green gram; Bg-Black gram; Sb-Soybean; F_1-Full dose of FYM & N, no P, full K (FYM @ 25 t/ha; NPK @ 100:0:150 kg/ha); F_2-Half dose of FYM & N, no P, full K (FYM @ 12.5 t/ha; NPK @ 50:0:150 kg/ha)

However, during unfavourable season (lesser rainfall and rainy days) the potential of intercropping system will be realized more (Nedunchezhiyan et al., 2021b).

All the intercropping systems studied were biologically efficient. The LER of the intercropping systems was more than 1 (Fig. 15). The highest ATER in T_4-taro + maize (5:1), indicated that growth requirement of both the component crops differed in time resulting in higher per day yield of the system due to temporal complementary effect. Thus, the advantage of intercropping system disappeared in T_5-taro + maize (5:2), T_6-taro + pigeon pea (5:1) and T_7-taro + pigeon pea (5:2) when evaluated via ATER concept (Fig.15). Considering yield (16.90 t/ha) and net return (₹ 1,48,500), taro + maize intercropping system (5:1) can be recommended for cultivation as a crop diversification option under rainfed conditions of eastern India with lower risk (Nedunchezhiyan et al., 2024).The intercropping system taro + pigeonpea (5:1) can also be considered when more emphasis needs to be given to soil health (Nedunchezhiyan et al., 2024) (Table 17).

Taro + maize (5:1) intercropping system

Taro + pigeonpea (5:1) intercropping system

Fig. 14. Promising taro + grain crop intercropping systems

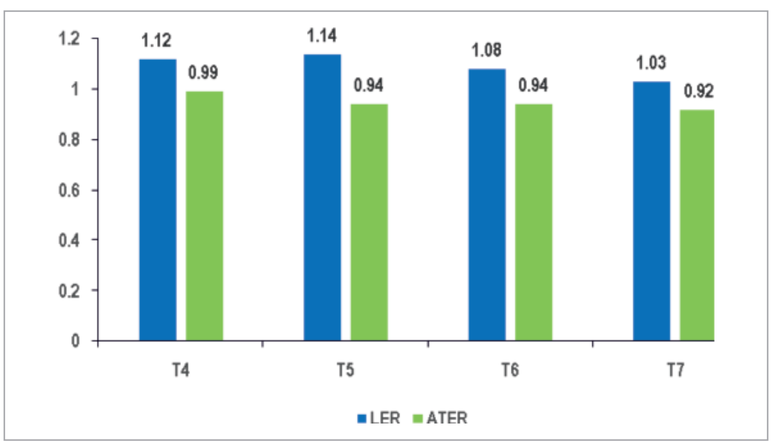


Fig. 15. LER and ATER of intercropping system

Table 17. Cormel equivalent yield and economics of taro + grain crop intercropping systems

Treatments	Cormel equivalent yield (t/ha)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Sole taro	18.59	111400	278900	167500	2.50
Sole maize	4.86	55200	72900	17700	1.32
Sole pigeonpea	7.00	50600	105100	54500	2.07
Taro + maize (5:1)	16.90	105000	253500	148500	2.41
Taro + maize (5:2)	15.19	99900	227800	127900	2.28
Taro + pigeonpea (5:1)	16.64	104100	249700	145600	2.40
Taro + pigeonpea (5:2)	14.37	98800	215600	116800	2.18
CD (0.05)	2.05	8200	30800	27800	0.27

Source: Nedunchezhiyan et al. (2021b)

In a lowland ecosystem at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, India, intercropping taro with pulse crops over two years produced yield (6.01 t/ha) equivalent to that of sole cropping (5.68 t/ha) with 5.68% increase (Fig. 16). Taro var. Sree Kiran was superior to Sree Rashmi with 14.56% higher yield under intercropping. Sree Kiran intercropped with green gram or black gram at the reduced nutrient level produced significantly higher cormel equivalent yield (12.34 and 11.89 t/ha), production efficiency (68.55 and 66.03 kg/ha/day) and equivalent energy (45.66 and 44.69 × 10^3 MJ/ha respectively), higher net income (₹ 2,90,508 and ₹ 2, 78, 362 per ha), B:C ratio (2.72 and 2.59) and added profit (₹ 2,24,152 and 2,12,006 per ha) over sole taro (Table 18). Intercropping with pulse crops favoured the biochemical constituents of cormels, viz., dry matter, starch and sugar and lowered the oxalate content in taro. The nutrient input to taro also could be reduced by half without significantly affecting the soil chemical properties, providing practical insights for wider adoption of the system (ICAR-CTCRI, 2018; 2019; 2020).

Table 18. System productivity and profitability as affected by intercropping systems involving taro and nutrient levels (Pooled mean of two years)

Cropping systems and fertility levels	Cormel yield (t/ha)	Pulse yield (kg/ha)	Cormel equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Net income (₹/ha)	Added profit (₹/ha)	B:C ratio
SK+GG (F1)	5.79	582.39	7.24	40.24	114738	48381	1.65
SK+GG (F2)	11.22	448.07	12.34	68.55	290508	224152	2.72
SK+BG (F1)	5.45	858.77	7.53	41.83	134389	68033	1.74
SK+BG (F2)	10.38	622.06	11.89	66.03	278362	212006	2.59
SK+SB (F1)	3.56	767.24	6.12	33.99	106900	40543	1.62
SK+SB (F2)	4.75	816.79	7.47	41.50	164172	97816	1.99
SR+GG (F1)	4.84	537.94	6.18	34.36	74906	29727	1.43
SR+GG (F2)	6.39	462.22	7.54	41.91	123557	78378	1.73
SR+BG (F1)	4.30	767.41	6.16	34.20	80795	35617	1.45
SR+BG (F2)	5.21	845.27	7.25	40.29	129705	84527	1.74
SR+SB (F1)	6.32	880.66	9.26	51.44	226242	181064	2.32
SR+SB (F2)	3.87	586.50	5.83	32.38	87521	42343	1.53
Sree Kiran (sole)	5.99		5.99	33.26	66356		1.46
Sre Rashmi (sole)	5.38		5.38	29.90	45178		1.32
CD (0.05) Varieties × pulse × fertility levels	NS	NS	NS	NS			
CD (0.05) Control vs treatment	NS	NS	0.943	5.241			

SK-Sree Kiran; SR-Sree Rashmi; GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full FYM & N, no P, full K (FYM @ 12.5 t/ha, NPK @ 80:0:100 kg/ha); F_2-Half FYM & N, no P, full K (FYM @ 6.25 t/ha, NPK @ 40:0:100 kg ha)

Taro + black gram

Taro + green gram

Taro + soybean

Fig. 16. Taro and pulse intercropping systems

Taro being a long duration crop, it takes 5-6 months to realize returns. Growing short duration vegetable crops as intercrop in taro will help to get returns quickly and also augment farm income. Under Bhubaneswar condition, Nedunchezhiyan & co-workers reported that growing of short duration vegetable cowpea or cluster bean as an intercrop in taro (Fig. 17) resulted in higher system productivity than sole crops of taro, okra, vegetable cowpea and cluster bean (Table 19) (ICAR-CTCRI, 2023). All the intercropping systems were biologically efficient with LER more than 1 (Fig. 18). Though the corm and cormel yield of taro in intercropping system was reduced compared to sole taro cultivation (Fig. 19), taro + vegetable cowpea/cluster bean (1:1) intercropping system was found to be suitable for smallholder farming system to achieve food and nutritional security and livelihood security due to higher income.

Sole taro cultivation

Taro + vegetable cowpea intercropping system

Fig. 17. Taro and vegetable intercropping systems

Table 19. System productivity of taro-vegetable intercropping systems

Treatments	System productivity (kg/ha)
Sole taro	17417
Sole okra	13328
Sole vegetable cowpea	11606
Sole cluster bean	9360
Taro + okra (1:1)	17097
Taro + vegetable cowpea (1:1)	22628
Taro + cluster bean (1:1)	18727

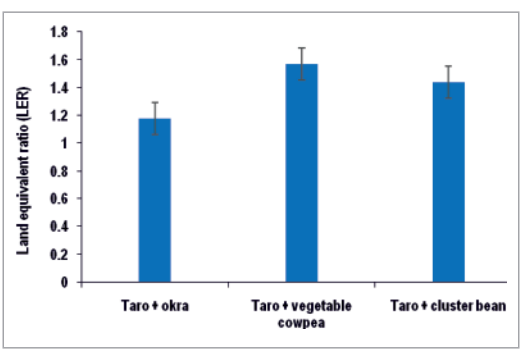


Fig. 18. LER of taro-vegetable intercropping systems

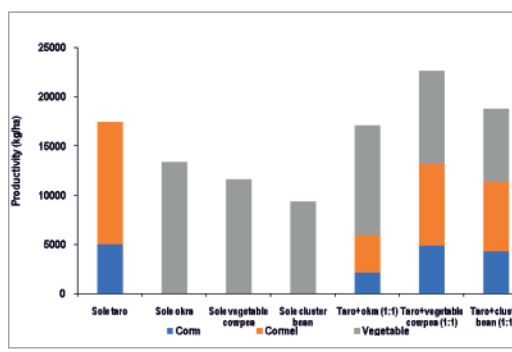


Fig. 19. Corm and cormel yield of taro and yield of vegetables in taro based intercropping systems

Intercropping in yam bean

Yam bean is propagated by seed and usually grown as a sole crop. Intercropping yam bean with cereals (like maize) is widely practiced to improve yield, resource use efficiency, and system productivity (Ayilara et al., 2023). Yam bean + sweet potato intercropping also help to reduce sweet potato weevil incidence.

5. Sequential Cropping Systems Involving Tropical Tuber Crops

Sequential cropping systems involving tropical tuber crops refer to the practice of growing two or more crops in a sequence on the same piece of land within a year. In these systems, tuber crops such as cassava, sweet potato, elephant foot yam, taro and Chinese potato are cultivated either before or after short-duration crops like pulses, cereals, or vegetables. This approach ensures efficient use of time, land, and resources, while maintaining soil productivity. Sequential cropping helps farmers obtain multiple harvests, diversify income, and reduce the risk of crop failure. It is particularly beneficial in tropical regions where favorable climatic conditions allow continuous cropping throughout the year.

Cassava in sequential cropping systems

Cassava, sweet potato, elephant foot yam or taro can be grown as sequential crops in rice fallows (Mohankumar and Nair, 1990). In rainfed single-crop rice fields (dry sown rice during *kharif* followed by fallow), rice-cassava cropping sequence appeared to be promising (Mohankumar et al., 1985). In double-crop rice fields (rice followed by rice) cropping sequence of cowpea (var. 61-8) followed by cassava (var. Sree Visakham) and elephant foot yam + vegetable cowpea followed by vegetable cowpea were found to be more profitable crop sequences.

The normal duration of cassava is 9-24 months and most of the varieties give the maximum targeted yield at 10-12 months. Presently much emphasis is given to crop diversification, to increase productivity especially under climate change. Hence, there is a preference for early-maturing varieties of cassava (6-7 months) as a sequential crop with rice, banana or vegetables particularly in lowlands (Mohankumar and Nair, 1990). There are large areas left fallow after rainfed rice, and even irrigated rice, when there is inadequate irrigation water for year-round cropping. Short-duration cassava varieties proved promising for better utilization of resources, diversification of food basket and income (Suja et al., 2010a; Suja et al., 2010b; Suja et al., 2011; Suja and Sreekumar, 2015; Byju and Suja, 2020).

Selection of cassava varieties and nutrient management

Research work carried out for over two decades (2003-2025) at ICAR-CTCRI, Thiruvananthapuram, Keralam, indicated that short-duration cassava varieties, Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka hold promise for crop intensification (Suja et al., 2010a; Byju and Suja, 2020). Triploid 2-18 (later released as Sree Athulya) gave the highest yield (38.34 t/ha), followed by triploid 4-2 (later released as Sree Apoorva), Sree Vijaya, Sree Jaya and Vellayani Hraswa, which were on a par (30–32 t/ha). The diploids Sree Vijaya, Sree Jaya, Vellayani Hraswa and Kalpaka are ideal for cultivation in rice fallows for food purpose owing to their high yield, good cooking quality and low cyanogen content. The triploids are better suited for industrial use owing to their high tuberous root dry biomass production (330.6, 374.1mg/g respectively) and fairly high starch content (253, 284.6 mg/g respectively).

Table 20. Short-duration cassava varieties as affected by nutrient levels (Pooled mean of three years)

Treatments	Tuber yield (t/ha) (pooled mean)	Cost of cultivation (₹/ha)	Net income (₹/ha)	B:C ratio
Varieties				
Kalpaka	21.81	56658	8765	1.16
Sree Jaya	20.74	56658	5547	1.10
Sree Vijaya	23.04	56658	12462	1.22
Triploid 2-18	28.45	56658	28767	1.51
Vellayani Hraswa	24.77	56658	17645	1.31
CD (0.05)	2.866			
Fertility levels				
Full FYM+NPK	25.05	59256	15894	1.27
75% FYM+NPK	23.48	56098	14342	1.26
50% FYM+NPK	22.33	52750	14300	1.27
Based on soil test data (FYM @ 12.5 t/ha and NPK @ 90:0:85 kg/ha)	24.18	58528	14012	1.24
CD (0.05)	1.389			

Source: Suja et al. (2010b)

Nutrient management based on soil test data that resulted in saving of the entire quantity of P, 10% N and 15% K (FYM @ 12.5 t/ha and NPK @ 90:0:85 kg/ha) produced higher tuber yield (24.18 t/ha), dry matter and starch content of tubers and positive soil nutrient balance (Suja et al., 2010b; Suja et al., 2011) (Table 20) for short-duration cassava in such systems.

Sequential cropping proved superior to intercropping as indicated by the significantly higher fresh tuber yield (26.07 t/ha under sequential cropping over 19.94 t/ha in intercropping) and dry matter production. Sequential cropping enhanced yield by 4%, whereas intercropping reduced yield by 20.36% over sole cropping. As expected, sequential cropping produced higher yield than sole cropping (by 4%) and intercropping (by 30.74%) in short-duration cassava as the cassava crop benefitted from the residual nitrogen fixed by cowpea as well as organic matter added by cowpea residues after its harvest as reported by Njoku and Muoneke (2008). Both vegetable cowpea (var. Pusa Komal) and grain cowpea (var. C-152) were equally compatible with short-duration cassava under both the systems. Entire P and half N for short-duration cassava (N: P_2O_5: K_2O @ 50:0:100 kg/ha) could be saved in both the systems involving cowpea by the third year. However, sequential cropping of vegetable cowpea with short-duration cassava under full N was a feasible option (tuber yield 27.32 t/ha) as it enabled saving of entire P for cassava and was profitable (net return ₹ 97,398 per ha and benefit: cost ratio 2.15) (Table 21) (Suja and Sreekumar, 2015).

Table 21. Economic analysis of short-duration cassava and cowpea system (Mean of three years)

Treatments	Cassava (t/ha)	Cowpea (kg/ha)	Gross income (₹/ha)	Gross costs (₹/ha)	Net income (₹/ha)	B:C ratio
VC - Cassava + full N	27.32	2500	181954	84556	97398	2.15
VC - Cassava + half N	25.94	1918	154521	83156	71365	1.86
GC - Cassava + full N	26.33	815	127875	74256	53619	1.72
GC - Cassava + half N	24.69	750	119080	73656	45424	1.62
Cassava + VC + full N	21.51	1100	108517	70256	38261	1.54
Cassava + VC + half N	19.30	880	93090	69656	23434	1.34
Cassava + GC + full N	20.70	530	93904	66256	27648	1.42
Cassava + GC + half N	18.28	428	80503	65656	14847	1.23
Sole cassava + full N	25.04		75119	59256	15863	1.27

Source: Suja and Sreekumar (2015); VC-Vegetable cowpea; GC-Grain cowpea

1. Rice - pulse - cassava system

Suja et al. (2025b) reported that rice-pulse-short-duration cassava was productive, profitable, energy efficient and nutrient saving based on detailed investigations done for two years on growth, biomass, productivity, quality and soil nutrient status. Rice var. Aiswarya was sown during the first season followed by pulses, green gram (var. Co-Gg-7), black gram (var. Co-6) and soybean (var. JS-95-60). Thereafter, short-duration cassava was planted in split plot design with two varieties, Sree Vijaya and Vellayani Hraswa, in main plots and combination of the three preceding pulses and two fertility levels to cassava (full farmyard manure (FYM), N and K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); half FYM and N, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha)) in subplots (Fig. 20). Both Vellayani Hraswa and Sree Vijaya were suitable for crop intensification. The pulse crops, green gram, black gram and soybean were equally compatible.

First crop of rice: var. Aiswarya

Second crop: Green gram: Co-Gg-7

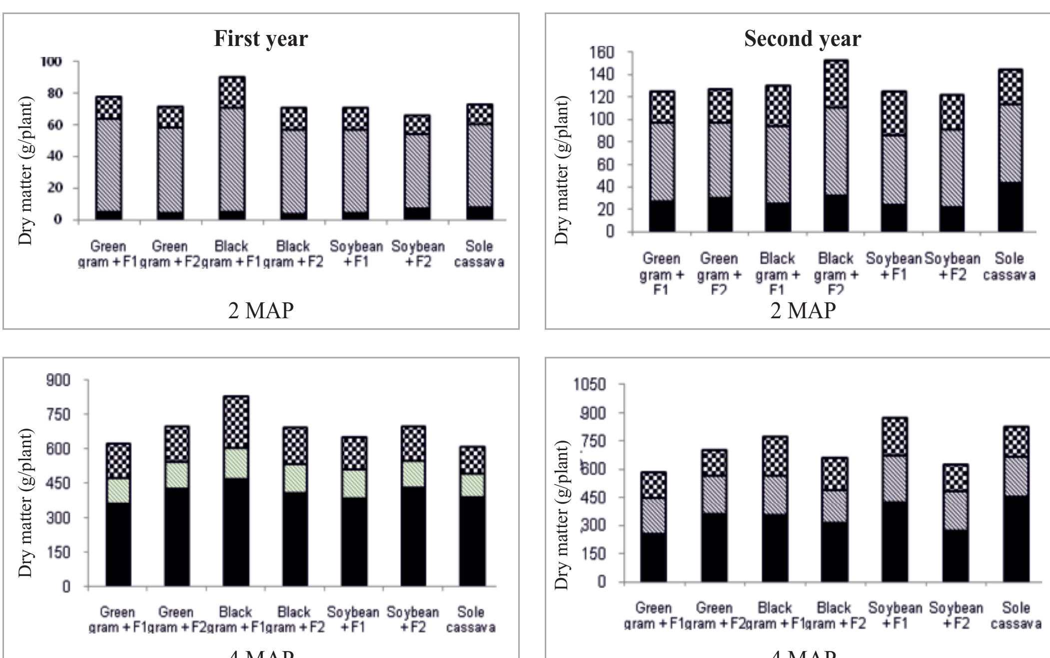
Second crop: Black gram: Co-6

Third crop: Short-duration cassava

Fig. 20. Rice - pulse - cassava system

The phasic trend of total dry matter production and partitioning to leaf, stem and tuber as influenced by pulse and fertility level is given in Fig. 21. In the first year, the main effect of pulse was significant for tuber biomass and mean tuber bulking rate (TBR), with soybean outperforming. The interaction effect between pulse and fertility level was significant for tuber biomass at 2 MAP, total biomass at 4 MAP and tuber and total biomass at 6 MAP. The total biomass production and its partitioning to leaf, stem and tuber at 2 and 4 MAP was higher, when black gram preceded and cassava was fertilized at the full dose. By 6 MAP (harvest stage), these attributes were favoured when soybean preceded and cassava was fertilized at the full dose (Fig. 21). At harvest, the total and tuber biomass production, crop growth rate, tuber bulking rate, mean tuber bulking rate, relative growth rate and harvest index of short-duration cassava were significantly higher when soybean preceded and cassava was fertilized at the full dose (Table 22, Fig. 21, Fig. 22). As expected, pulse crops prior to cassava were beneficial for its growth compared to sole cassava.

In the subsequent year, at 2 MAP, the total dry matter production and its partitioning to leaf, stem and tuber were higher in cassava fertilized at reduced level of fertility and preceded by black gram. Thereafter, sole cassava outperformed over the different cropping systems (Fig. 21). At harvest, the tuber biomass production (14.24 t/ha) and total biomass production (19.37 t/ha) of sole cassava was higher, which was on par with that of cassava under reduced level of fertility preceded by black gram (BG + F2) (10.04, 15.91 t/ha respectively) (Table 22). The crop growth rate (CGR), tuber bulking rate (TBR) and harvest index (HI) of sole cassava was higher throughout the different stages (Fig. 22). Mean TBR of black gram + F1 (5.25 g/day) and soybean + F1 (5.48 g/day) were on par with that of sole cassava (5.28 g/day) (Table 22). In the first phase (2-4 MAP), the relative growth rate (RGR) of cassava in systems preceded by all the pulses was equivalent to sole cassava. In the second phase (4-6 MAP), RGR of cassava in systems preceded by black gram and green gram was similar to that of sole cassava (Fig. 22). This indicates the scope of sequential cropping of rice, pulses and cassava.



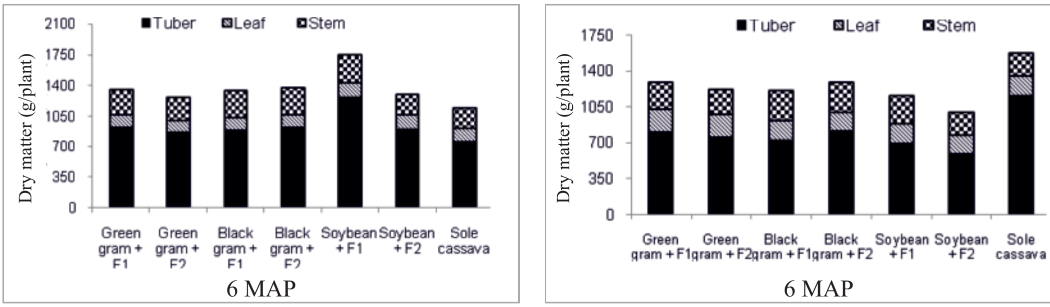


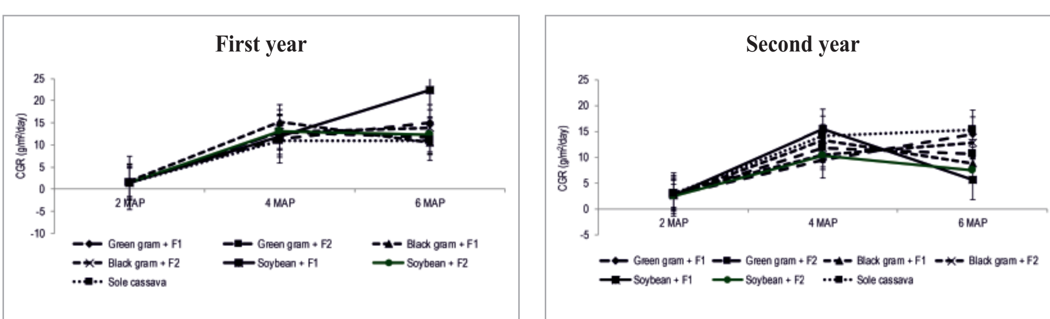
Fig. 21. Interaction effect between pulse crops and fertility levels on biomass production and partitioning at various phases in cassava in rice - pulse - cassava system

Source: Suja et al. (2025b)

Table 22. Interaction effect between pulse crops and fertility levels on biomass production of cassava

Interaction effect between pulse and fertility level	Tuber biomass (t/ha)		Total biomass (t/ha)		Mean tuber bulking rate (g/day)	
	First year	Second year	First year	Second year	First year	Second year
Green gram + F1	11.41	9.88	16.74	15.87	5.14	4.28
Green gram + F2	10.66	9.19	15.59	15.02	4.80	4.60
Black gram + F1	10.98	8.92	16.53	14.87	4.94	5.25
Black gram + F2	11.30	10.04	16.91	15.91	5.09	4.87
Soybean + F1	15.64	8.53	21.51	14.20	7.04	5.48
Soybean + F2	11.10	7.28	15.95	12.22	4.99	4.25
Sole cassava	9.37	14.24	14.11	19.37	4.22	5.28
CD (0.05)	2.865††	4.736†	4.039††	5.631†	1.289††	0.165††

Source: Suja et al. (2025b); F_1-Full dose of FYM, N&K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); F_2-Half FYM and N, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha); Control vs treatment; †† pulse x fertility level



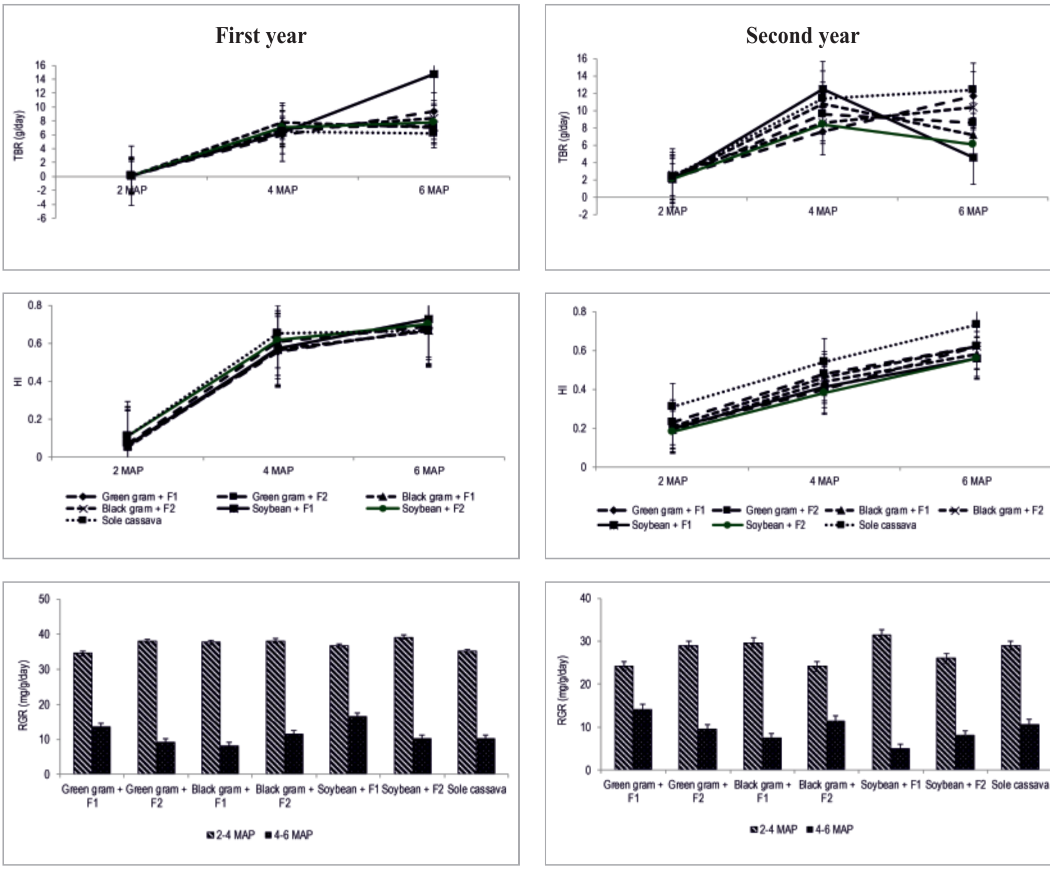


Fig. 22. Growth parameters of cassava at various stages as affected by pulse crops and fertility levels in rice - pulse - cassava system. Source: Suja et al. (2025b)

The nutrient status of soil, pH, organic C, available N, P and K were not significantly affected, but were higher due to pulse cropping. Averaging over two years, the tuber yield of cassava (30.82 t/ha), tuber equivalent yield (47.39 t/ha), production efficiency (131.63 kg/ha/day), energy equivalent (234.07 × 10^3 MJ/ha) and profit (net return, ₹ 45,8531/ha; added profit of ₹ 95,759/ha over sole cassava) were higher for rice (var. Aiswarya)-blackgram (var. Co-6)-short-duration cassava (var. Sree Vijaya) system at the reduced nutrient level, resulting in a saving of half FYM and, N and full P (Table 23).

Table 23. Productivity and profitability of rice - pulse - cassava system (Mean of two years)

Cropping system & fertility level	Yield			Tuber equivalent yield (t/ha)	Net return (₹/ha)	Added profit (₹/ha)	B:C ratio
	Rice (t/ha)	Pulse (kg/ha)	Cassava (t/ha)				
R-GG-SV (F1)	4.34	727.24	28.48	43.57	374386	11614	2.80
R- GG-SV (F2)	4.10	715.30	26.56	40.98	345422	-17351	2.70
R- BG-SV (F1)	4.20	1177.09	28.81	45.69	428215	65443	3.06
R- BG-SV (F2)	4.23	1108.68	30.82	47.39	458531	95759	3.26
R- SB-SV (F1)	4.05	757.63	27.96	42.19	362836	63.63	2.74
R- SB-SV (F2)	3.98	720.25	25.67	39.50	329894	-32879	2.63
R-GG-VH (F1)	4.32	710.08	26.91	41.84	349295	-44377	2.68
R- GG-VH (F2)	4.07	709.25	29.77	44.06	392478	-1194	2.93
R- BG-VH (F1)	4.32	1025.33	23.79	40.14	342567	-51105	2.64
R- BG-VH (F2)	3.98	930.38	26.76	41.74	377654	-16019	2.86
R- SB-VH (F1)	4.25	705.58	24.67	39.12	314103	-79570	2.51
R- SB-VH (F2)	4.11	687.75	19.13	33.13	232381	-161291	2.15
Sree Vijaya (sole)			31.16	31.16	362772		4.47
Vellayani Hraswa (sole)			33.22	33.22	393672		4.76

Source: Suja et al. (2025b); R-Rice; SV-Sree Vijaya; VH-Vellayani Hraswa; GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full dose of FYM, N&K(FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); F_2-Half FYM and N, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha)

2. Rice -cassava + pulse system

Rice var. Kanchana was initially planted, followed by short-duration cassava (var. Sree Vijaya and Vellayani Hraswa) intercropped with pulse crops, green gram (var. Co-Gg-7), black gram (var. Co-6), and soybean (var. JS-95-60) under two fertility levels. Sustainable crop intensification through rice - cassava + pulse intercropping system, as a soil management strategy, could considerably improve the productivity, soil organic C content and nutrient use efficiency (Suja et al., 2025c; Suja et al., 2025d).

Across both years, cropping system treatments (variety × pulse × nutrient level) showed no significant impact on total biomass production or distribution to leaf, stem, or tuber during various growth stages. This suggests a consistent pattern of biomass distribution regardless of cassava variety, pulse intercrop, or fertility level. In the first year, no significant difference was observed between sole cassava and cropping system treatments in terms of tuber dry matter at 2 and 4 MAP. However, at these stages, total dry matter under sole cassava cultivation was comparable to cassava (var. Sree Vijaya) grown with reduced fertility and intercropped with black gram.

By harvest, total and tuber biomass under sole cropping was on par with cassava (var. Vellayani Hraswa) intercropped with black gram at full fertility level (Fig. 23). In the following year, sole cassava versus treatment at 2 and 4 MAP did not significantly influence dry matter distribution. However, at 6 MAP, total biomass and tuber partitioning were higher under sole cropping, similar to most cropping system treatments, except for Sree Vijaya intercropped with green gram at full or half fertility levels and Vellayani Hraswa intercropped with soybean at full fertility level (Fig. 23). This suggests similar efficiency of most of the cropping system treatments to that of sole cropping.

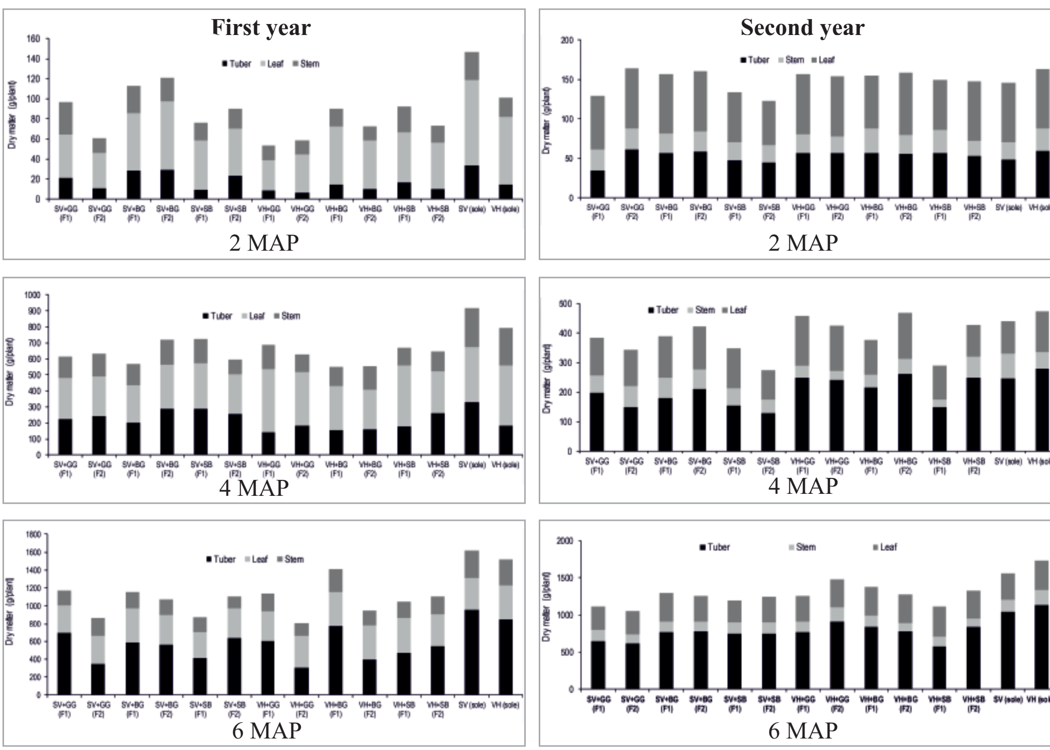


Fig. 23. Interaction effect between pulse crops and nutrient levels on biomass production and partitioning at various phases in cassava

Source: Suja et al. (2025d)

Over two years, intercropping Sree Vijaya or Vellayani Hraswa cassava with black gram under reduced fertilizer level produced similar cassava tuber yields (25.94 t/ha; - 19.39%) compared to sole cassava (32.18 t/ha). These yield reductions in cassava may be attributed to its poor competitive ability during early growth stages when intercropped with pulse crops, consistent with observations by Nwokoro et al. (2021) in cassava-maize intercropping systems. Intercropping short-duration cassava with short-duration pulses presents an opportunity, as the reduction in cassava yield (26% average over two years) could be offset by additional yield and soil health benefits from the legume. Short-duration cassava variety Sree Vijaya exhibited better tolerance to competitive stress (yield reduction of 22%) and greater compatibility than Vellayani Hraswa (yield reduction of 30%).

All the pulse crops tested, green gram, black gram, and soybean were suitable for intercropping with short-duration cassava. Rice var. Kanchana followed by short-duration cassava var. Sree Vijaya + black gram var. Co-6 was productive (tuber yield, 26.67 t/ha; tuber equivalent yield, 40.19 t/ha ; production efficiency, 111.64 kg/ha/day), energy efficient (191.11 × 10^3 MJ/ha) and profitable (net return, ₹ 41,6531/ha; added profit of ₹ 61,736/ha over sole cassava), besides saving half FYM and N and all P (Table 24, Fig. 24).

Table 24. Productivity and profitability of rice - cassava + pulse system (Mean of two years)

Cropping system & fertility level	Yield			Tuber equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Equivalent energy (*10^3 MJ/ha)	Net return (₹/ha)	Added profit (₹/ha)
	Rice (t/ha)	Pulse (kg/ha)	Cassava (t/ha)					
R-SV+GG (F1)	2.75	445.05	23.19	34.12	94.77	166.60	308083	-46712
R-SV+GG (F2)	2.85	425.10	22.09	33.11	91.97	161.35	299466	-55328
R-SV+BG (F1)	2.75	655.00	24.18	37.00	102.78	174.61	362688	7893
R-SV+BG (F2)	2.95	675.00	26.67	40.19	111.64	191.11	416531	61736
R-SV+SB (F1)	2.75	350.10	23.83	35.65	99.02	169.10	342383	-12412
R-SV+SB (F2)	2.75	325.00	24.01	35.49	98.58	169.78	346006	-8789
R-VH+GG (F1)	2.75	425.00	23.53	33.57	93.25	168.30	311213	-85957
R-VH+GG (F2)	2.85	395.00	22.76	32.86	91.27	164.78	306521	-90649
R-VH+BG (F1)	2.75	525.00	24.89	36.59	101.64	177.09	356513	-40657
R-VH+BG (F2)	2.75	585.25	25.21	37.43	103.98	179.59	375164	-22006
R-VH+SB (F1)	2.75	325.00	21.46	32.94	91.51	155.53	301813	-95357
R-VH+SB (F2)	2.75	310.00	23.70	34.98	97.18	167.90	338431	-58739
Sree Vijaya (sole)			30.76	30.76	85.44	172.26	354795	
Vellayani Hraswa (sole)			33.59	33.59	93.29	188.08	397170	

Source: Suja et al. (2025c; 2025d); R-Rice; SV-Sree Vijaya; VH-Vellayani Hraswa; GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full dose of FYM & N, no P, full K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); F_2-Half dose of FYM & N, no P, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha)

Fig. 24. Rice - cassava + pulse system

The N, P and K uptake by cassava at harvest was higher for sole cassava, which was on par with cassava (either of the varieties) intercropped with black gram at full nutrient level (Fig. 25).This may be attributed to the almost similar total biomass production in sole cassava and the intercropping treatment, which suggest the feasibility of intercropping pulse crops with short-duration cassava in rice-based system.

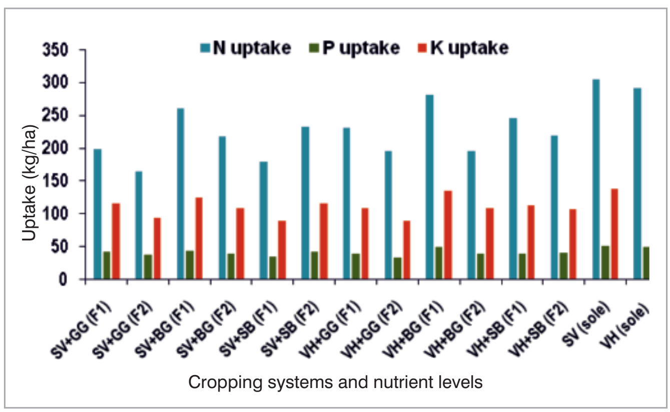


Fig. 25. Effect of cropping systems and nutrient levels on nutrient uptake of cassava

Source: Suja et al. (2025c)

Cropping system treatments (variety x pulse x fertility level) did not significantly affect tuber biochemical composition. Control versus treatment significantly impacted tuber dry matter and cyanogenic glucoside contents (Table 25). However, the dry matter content of tubers was significantly higher in all the intercropping treatments involving Vellayani Hraswa, except that intercropped with green gram at the reduced fertility level, over sole Vellayani Hraswa. Among these, Vellayani Hraswa intercropped with black gram at full fertility level resulted in highest tuber dry matter content (41.23%). Cyanogenic glucoside content varied significantly among treatments, with Vellayani Hraswa intercropped with green gram at full fertility level showing the lowest content (13.68%). Most of the cropping system treatments resulted in comparably low cyanogenic glucoside contents similar to sole cassava, except that under soybean intercropping. The starch, total sugar, and crude protein content of tubers remained unaffected (Table 25). The study conclusively demonstrates that early competition effects from intercropping do not compromise tuber quality.

In the first year, the soil chemical properties, pH and available N were higher under intercropping with pulse crops, especially black gram/green gram; organic C, available P and K were not significantly affected, but higher under intercropping (Table 26). In a number of studies, the integration of legumes like cowpea, groundnut, soybean, pigeonpea with cassava significantly influenced the major soil nutrients, total N, available P and soil organic carbon (Ravi et al., 2021).

Table 25. Effect of cropping systems and nutrient levels on biochemical composition of tubers of cassava (Average of two years)

Cropping systems and fertility levels	Dry matter (%)	Starch (% FW basis)	Total sugar (% FW basis)	Crude protein (% FW basis)	Cyanogenic glucoside (μg/g)
SV+GG (F1)	36.27	22.12	1.12	1.52	21.10
SV+GG (F2)	36.18	22.19	1.73	1.27	22.63
SV+BG (F1)	37.47	22.54	1.79	1.60	24.60
SV+BG (F2)	36.25	23.50	1.64	1.55	23.83
SV+SB (F1)	37.74	21.29	1.66	1.65	26.98
SV+SB (F2)	38.42	21.13	1.31	1.91	29.84
VH+GG (F1)	39.39	23.08	1.20	1.92	13.68
VH+GG (F2)	38.29	23.32	1.23	1.78	20.31
VH+BG (F1)	41.23	24.40	1.26	2.05	20.56
VH+BG (F2)	39.35	23.95	1.31	2.02	17.30
VH+SB (F1)	39.68	25.40	1.07	2.04	17.31
VH+SB (F2)	38.67	26.07	1.32	1.96	26.34
SV (sole)	40.91	22.54	1.54	1.59	17.67
VH (sole)	38.96	22.57	1.15	1.86	19.34
CD (0.05)					
Variety × pulse × fertility level	NS	NS	NS	NS	NS
Control vs treatment	0.92	NS	NS	NS	8.255

Source: Suja et al. (2025d); R-Rice; SV-Sree Vijaya; VH-Vellayani Hraswa; GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full dose of FYM & N, no P, full K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); F_2-Half dose of FYM & N, no P, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha)

In the subsequent year, available N and P status were significantly higher under Sree Vijaya intercropped with soybean at reduced fertility level and Vellayani Hraswa with green gram at full fertility level respectively. Available K was significantly reduced due to intercropping. Similar result of decrease in exchangeable K in soil under cassava intercropping with legumes like cowpea, groundnut, pigeonpea or soybean was attributed to removal of K from the soil by these two crops (Ajeigbe, 2003; Farinu, 2006). The soil pH and organic C were not significantly influenced by the treatments (Table 26).

Thus, the increase in available N, and available P in the cassava + pulse crop system may be due to the fast rate of decomposition and high rate of mineralization of the leaf biomass that was returned from the legume during the growing period and incorporation of legume crop residue after harvest of grains, their low C:N ratio and the ability of legumes to fix large quantities of N into the soil. Similar results have been documented by several earlier researchers (Kim, 2005; Aigh, 2007). Thus, legumes are highly compatible with cassava in terms of growth pattern, canopy development, shorter crop duration (3 months), and nutrient demands, as they require mostly P and can get part of their N requirement through biological nitrogen fixation (BNF) (Giller, 2001), while cassava requires large amounts of K for storage root formation and N for leaf production (Howeler, 2002; Carsky and Toukourou, 2005).

Table 26. Effect of cassava + pulse system and nutrient levels on major chemical properties of soil

Cropping systems and fertility levels	pH		Organic C (%)		Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year
SV+GG (F1)	4.18	4.53	0.95	0.76	163.6	60.63	19.87	61.39	152.10	154.90
SV+GG (F2)	4.30	4.62	0.84	0.73	136.2	47.04	15.60	44.34	122.90	212.10
SV+BG (F1)	4.54	4.53	0.80	0.74	147.8	34.50	20.64	97.73	151.70	217.10
SV+BG (F2)	3.99	4.66	0.85	0.78	142.5	45.47	14.89	68.09	276.70	202.20
SV+SB (F1)	4.28	4.75	0.78	0.62	153.1	63.77	21.10	73.84	156.40	240.40
SV+SB (F2)	4.27	4.66	0.79	0.53	132.0	94.08	13.76	43.90	203.20	219.60
VH+GG (F1)	4.39	4.87	0.81	0.60	195.3	64.29	13.60	101.56	182.70	204.90
VH+GG (F2)	4.55	4.50	0.77	0.56	137.3	70.56	16.07	59.68	168.50	212.90
VH+BG (F1)	4.86	4.76	0.74	0.72	142.5	79.97	15.25	74.43	158.30	274.60
VH+BG (F2)	4.45	4.62	1.00	0.54	155.7	76.83	13.86	91.83	216.80	182.00
VH+SB (F1)	4.35	4.85	1.05	0.42	150.4	84.15	14.53	82.72	187.00	176.40
VH+SB (F2)	4.12	4.53	0.86	0.60	154.4	73.70	12.88	75.17	139.60	149.30
SV (sole)	4.02	4.54	0.75	0.67	110.9	47.04	13.19	50.10	194.40	280.90
VH (sole)	3.81	4.67	0.82	0.59	108.2	62.72	14.48	47.00	121.40	322.90
CD (0.05)	NS	0.067	NS	0.06	NS	7.290	NS	15.739	NS	22.258
Variety × pulse × fertility level										
Control vs treatment	0.531	0.067	NS	NS	50.92	7.290	NS	15.739	NS	22.258

Source: Suja et al. (2025c); R-Rice; SV-Sree Vijaya; VH-Vellayani Hraswa; GG-Green gram; BG-Black gram; SB-Soybean; F_1-Full dose of FYM & N, no P, full K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ha); F_2-Half dose of FYM & N, no P, full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha)

3. Rice - cassava + legume/oilseed system

Rice var. Manu Ratna was sown in first season followed by short-duration cassava (var. Sree Vijaya and Vellayani Hraswa) intercropped with leguminous vegetables (cluster bean (var. Gloria), French bean (var. Crystal) and oilseed crop (groundnut var. Co-7) under two nutrient levels for cassava [full FYM, full N, no P and full K (FYM @ 12.5 t/ha, NPK @ 100:0:100 kg/ ha); half FYM, half N and full K (FYM @ 6.25 t/ha, NPK @ 50:0:100 kg/ha (Fig. 26). Averaging over two years, of the three systems involving legumes, rice-short-duration cassava (var. Vellayani Hraswa) + cluster bean (var. Gloria) was the most productive (tuber yield, 21.97 t/ha; tuber equivalent yield, 34.28 t/ha; production efficiency, 95.21 kg/ha/day), energy efficient (227.10×10^3 MJ ha^{-1}) and profitable (net return of ₹ 268,832 per ha, added profit of ₹ 130,311 per ha) and besides saving half FYM and N and all P to cassava (Table 27).

First crop of rice: Manu Ratna

Short duration cassava + cluster bean

Short duration cassava + French bean

Short duration cassava + groundnut

Fig. 26. Rice- cassava + legume/oilseed system

Table 27. Productivity and profitability of rice - cassava + legume/oilseed system

Treatments	Yield			Tuber equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Equivalent energy (*10^3 MJ/ha)	Net return (₹/ha)	Added profit (₹/ha)	B:C ratio
	Rice (t/ha)	Legume (kg/ha)	Cassava (t/ha)						
R-CB+SV (F1)	1.96	2149.92	19.50	30.54	84.84	198.87	206145	-1331	1.79
R-CB+SV (F2)	2.35	1215.99	20.85	30.76	85.43	217.19	216474	8998	1.86
R-FB+SV (F1)	2.28		16.20	23.04	64.01	185.36	93220	-114256	1.36
R-FB+SV (F2)	2.38		15.65	22.77	63.26	185.75	97805	-109672	1.39
R-GN+SV (F1)	2.28	820.42	15.04	28.50	79.16	200.87	175016	-32460	1.67
R-GN+SV (F2)	2.38	735.52	14.10	27.12	75.33	195.75	159946	-47530	1.63
R-CB+VH (F1)	2.25	2836.08	20.31	33.67	93.53	210.34	253113	114592	1.98
R-CB+VH (F2)	2.38	2210.51	21.97	34.28	95.21	227.10	268832	130311	2.07
R-FB+VH (F1)	2.25		16.06	22.93	63.70	187.01	92000	-46521	1.35
R-FB+VH (F2)	2.35		16.25	23.30	64.73	188.55	103189	-35332	1.41
R-GN+VH (F1)	2.25	844.47	18.43	31.98	88.84	219.10	227761	89240	1.88
R-GN+VH (F2)	2.25	668.29	14.55	26.73	74.25	194.08	156109	17588	1.62
Sole Sree Vijaya			23.00	23.00	63.89	128.81	207476		2.51
Sole Vellayani Hraswa			18.40	18.40	51.12	103.06	138521		2.01

R-Rice; SV-Sree Vijaya; VH-Vellayani Hraswa; CB-Cluster bean; FB-French bean; GN-Ground nut; F_1-Full dose of FYM & N, no P, full K (FYM@ 12.5 t/ha; NPK @ 100:0:100 kg/ha) F_2-Half dose of FYM & N, no P, full K (FYM@ 6.25 t/ha; NPK @ 50:0:100 kg/ha)

4. Rice - cassava - vegetable system

A field experiment was carried out for two seasons (2023-2025) in split plot design with short-duration rice var. Manu Ratna as first crop (June-August), followed by short-duration cassava (var. Sree Vijaya and Vellayani Hraswa) during the second season (September-February) in main plots and two nutrient levels in sub plots. There after vegetables (amaranthus (var. Vaika), cucumber (var. KAU Vishal) and water melon (var. Shonima) were sown under two nutrient levels during March-April (Fig. 27). Sole crop of cassava under full dose of manures and fertilizers were also maintained for comparison.

Averaging over two years, of the three systems involving vegetables, rice (var. Manu Ratna)-short-duration cassava (var. Sree Vijaya or Vellayani Hraswa)-cucumber (var. KAU Vishal) was the most productive with higher cassava tuber yields (26.75, 28.83 t/ha), tuber equivalent yield (92.56, 85.84 t/ha), production efficiency (257.11, 238.43 kg/ha/day) and energy equivalent (298.20, 305.67 × 10^3 MJ/ha respectively) at reduced nutrient levels (half FYM & N, zero P to cassava; half FYM, N & P to cucumber).

First crop of rice: Manu Ratna

Second crop of short-duration cassava

Third crop of vegetables

Fig. 27. Rice - cassava - vegetable system

Sweet potato in sequential cropping systems

Sweet potatoes figure in the intensive irrigated rice/paddy and sugarcane (*Saccharum officinarum* L.) based cropping systems of Taiwan (Nedunchezhiyan et al., 2012b). It is grown as winter crop after wet rice to be followed by another rice crop, groundnut/peanuts (*Arachis hypogaea* L.) or soybeans (*Glycine max* L. Merr.). In such system, sweet potato is planted directly into rice stubble or relay planted 20-30 days prior to rice harvesting. In sugarcane-based cropping system, sweet potato is interplanted (in between sugarcane rows of 1.25 m) during early-August at the time of planting cane setts.

In India, cropping systems involving sweet potato vary from region to region (Nedunchezhiyan et al., 2012b). In Odisha, common sequences are maize - sweet potato - fallow and rice - sweet potato - fallow. In Uttar Pradesh, sweet potato is usually grown as a kharif crop in sequence to cereals or pulses. For Bihar, maize (kharif) - sweet potato - onion (*Allium cepa* L.) are the recommended sequences. A net income as high as $ 444.4/ha is obtained from such cropping system. In south India, especially in the coastal belt, sweet potato is grown during summer following the second crop of rice. The sequences like rice -

rice - sweet potato; rice - sweet potato - rice and rice - sweet potato - cowpea (*Vigna unguiculata* L.) are profitable and capable of reducing weevil damage in sweet potato.

The rice - sweet potato-cowpea produced maximum returns ($ 740.2/ha) and was therefore the most economic cropping sequence, followed by rice - rice - sweet potato ($ 484.6/ha) and taro-sweet potato ($ 455.2/ha) (Nedunchezhiyan et al., 2012b). Rice - sweet potato - rice was also found economical ($ 442.5/ha). These treatments were also found to be highly effective to reduce sweet potato weevil (*Cylas formicarius* L.) infestation (Nedunchezhiyan et al., 2012b).

Sweet potato could successfully establish under zero tillage after harvest of rice under low land ecosystem (Nedunchezhiyan et al., 2013). Nedunchezhiyan et al. (2011b) reported that sweet potato can be planted under zero tillage immediately after harvesting of rice, when the soil is marshy (Fig. 28). In rainfed lowland rice fallow, under minimum tillage, variety Sourin, performed better than others (Nedunchezhiyan et al., 2013). The storage root of Sourin was short and elliptic with short neck. The storage roots develop bulking at shallow depth. These features led to more yield in Sourin variety. In rainfed lowland rice fallow, under conventional tillage the variety, Kishan, produced more yield (Nedunchezhiyan et al., 2013) (Table 28).

The study indicated that for higher cropping intensity and utilization of residual excess moisture, sweet potato crop can be grown in lowland rice fallow with irrigation and also in rice-fish system in deep water situation with the variety Kishan under conventional tillage and Sourin under minimum tillage conditions (Nedunchezhiyan et al., 2013). Though conventional tillage was better in the case of sweet potato crop in rainfed lowland rice fallow, for utilizing the residual excess moisture immediately after the rice harvest in rainfed lowland and also in rice-fish system in deep water areas minimum tillage method of crop establishment can be followed along with supplementing few irrigations. This practice is beneficial in terms of increasing cropping intensity, as though it yields 30% less storage root yield and about 10% less vine yield; it saves 20 days-time and 12 cm irrigation water compared to conventional tillage.

Fig. 28. Sweet potato in rice fallow

Table 28. Effect of tillage on yield of sweet potato varieties grown in sequence after rice

Treatments	Storage root yield (t/ha)	Vine yield (t/ha)	Harvest index
Method of tillage			
Minimum tillage (MT)	13.95	16.62	0.46
Conventional tillage (CT)	20.98	15.78	0.57
CD (0.05)	0.624	NS	0.04
Variety			
Sourin	17.29	15.65	0.52
Kalinga	15.31	15.30	0.50
Kishan	19.27	17.03	0.53
Samrat	17.98	16.83	0.52
CD (0.05)	0.936	NS	NS
Interaction			
MT x Sourin	15.22	17.12	0.47
MT x Kalinga	13.54	15.77	0.46
MT x Kishan	13.18	17.16	0.43
MT x Samrat	13.85	16.43	
CT x Sourin	19.36	14.17	
CT x Kalinga	17.09	14.82	
CT x Kishan	25.37	16.91	
CT x Samrat	22.12	17.23	
CD (0.05)	1.248	NS	

Source: Nedunchezhiyan et al. (2013); MT: Minimum tillage; CT: Conventional tillage

In rice-based cropping system in the coastal plains of Odisha, West Bengal, Karnataka, Tamil Nadu and Andhra Pradesh, sweet potato is planted after harvesting of rice to take advantage of the residual soil moisture and fertilizers (Nedunchezhiyan et al., 2012b). Sweet potato planted with minimum tillage in rice fallow required lower irrigation water than conventional method of planting (Nedunchezhiyan et al., 2013). In Odisha, rice - fallow - sweet potato is a popular three-year rotation in uplands, which minimizes weed infestation and sweet potato weevil incidence, rebuilding soil fertility status and resulting in more rice productivity (Nedunchezhiyan et al., 2012b).

A five-year field study was undertaken in the wetland rice fields of Cropping Systems Research Centre, Kerala Agricultural University, Thiruvananthapuram during 2006-2011 by Jacob John et al. (2013). From the stability analysis, ancillary observations and economic analysis over five years, it was inferred that rice - rice - amaranthus and rice - rice-sweet potato were the best cropping sequences. The highest average annual rice equivalent, net income and system profitability were obtained in the sequence rice - rice - amaranthus (32.76

t/ha, ₹ 216487/ha, ₹ 593.12/ha/day respectively), followed by rice - rice - sweet potato (21.92 t/ha, ₹ 151740/ha, ₹ 415.73/ha/day respectively).

In Bangladesh, sweet potatoes are grown mainly in river beds and Char areas (Nedunchezhiyan et al., 2012b). In these lands, only one crop of sweet potato is grown during October - November to March - April. However, in some relatively high-lands broadcasted *Aus* paddy is grown immediately after harvesting of sweet potato. Where the land is medium high, broadcasted *Aus* paddy - transplanted *Aman* paddy - sweet potato cropping pattern is followed.

In Sri Lanka, sweet potato is grown in sequence to rice or vegetables (Nedunchezhiyan et al., 2012b). Sowing of peanuts or winged bean (*Psophocarpus tetragonolobus* L.) in rotation with sweet potato reduced pest and disease incidence. Further, the same rotation was also followed to maintain soil fertility in Papua New Guinea (PNG) (Bourke and Ramakrishna, 2009). In some highlands of PNG, vegetables were rotated with sweet potato. In this system, vegetables were grown using fertilizers and the residues also benefit the subsequent sweet potato plantings (Bourke and Ramakrishna, 2009). Zou et al. (2020) reported changes in mycorrhizal colonization of citrus roots, when intercrops were grown. Sweet potato variety Sree Bhadra planted as preceding crop of flue cured virginia tobacco (*Nicotiana tobaccum* L.) nursery reduced 82.8% initial root-knot nematode soil population over control (Mohandas and Siji, 2012). Further, sweet potato grown beds resulted in 118.6% increase in yield over the control.

Sustainable cropping system models involving tuber crops

By combining or rotating tuber crops with cereals, legumes or vegetables, farmers can enhance soil fertility, particularly through biological nitrogen fixation, and reduce dependency on chemical inputs. In sustainable models, practices like crop rotation, use of organic manures, mulching, and minimal tillage are commonly adopted alongside tuber cultivation. For example, cassava intercropped with cowpea or followed by a leguminous vegetable crop, or yam grown with legumes and sweet potato rotated with cereals, helps to maintain soil health and break pest and disease cycles. These systems also improve resource-use efficiency by optimizing sunlight, water, and nutrients throughout the year. Such models are especially suitable for tropical regions like Keralam, where continuous cropping is possible due to favorable climate conditions. They provide multiple harvests, diversify farm income, and reduce risks associated with monocropping (Table 29). Overall, sustainable tuber crop-based cropping systems contribute to long-term agricultural productivity, environmental conservation, and livelihood security for farmers.

Table 29. Sustainable cropping system models involving tuber crops at a glance

Model No.	Cropping systems vs sole cropping	Tuber equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Equivalent Energy ($*10^3$ MJ/ha)	Net returns (₹/ha)	B:C ratio	Added profit (₹/ha)
1	Rice - black gram - cassava	47.39	131.63	234.07	458531	3.26	95759
	Sole cassava	31.16	86.56	174.50	362772	4.47	
2	Rice - cassava + black gram	40.19	111.64	191.11	416531	2.93	61737
	Sole cassava	30.76	85.44	172.26	354795	4.33	
3	Rice - cassava + cluster bean	34.28	95.21	227.10	268832	2.07	130311
	Sole cassava	18.40	51.12	103.06	138521	2.01	
4	Sweet potato + pigeon pea	13.53	82.00		28075		6253
	Sole sweet potato	13.37	114.42		21822		
5	Greater yam + maize	18.73	89.20				22055
	Sole greater yam	13.70	65.20				
6	Dwarf white yam + green gram	28.26	104.66	106.38	809095	3.52	183842
	Sole dwarf white yam	22.90	84.81	82.43	625253	3.15	
7	Elephant foot yam + ginger	39.60	146.67		233000	2.43	23000
	Sole elephant foot yam	36.00	133.33		210000	2.40	
8	Elephant foot yam + soybean	66.77	247.30	239.91	1009856	3.20	233164
	Sole elephant foot yam	46.48	172.15	167.33	776692	2.80	
9	Taro + maize	16.90	102.42		148500	2.41	
	Sole taro	18.59	112.66		167500	2.50	
10	Taro + green gram	12.34	68.55	45.66	290508	2.72	224152
	Sole taro	5.99	33.26	21.55	66356	1.46	

6. Summary and Conclusion

Crop diversification with tropical tuber crops such as cassava, sweet potato, yams, and aroids is increasingly recognized as a practical pathway to strengthen agricultural sustainability, profitability, and resilience in tropical farming systems. Integrating these crops into existing production systems helps address critical challenges such as climate variability, soil degradation, nutritional deficiencies, and income instability among smallholder farmers.

Research carried out by ICAR-Central Tuber Crops Research Institute and its Regional Station provides strong evidence that tuber crop-based cropping systems enhance land-use efficiency, cropping intensity, and overall farm productivity. Approaches such as intercropping, mixed cropping and sequential cropping, involving tuber crops have consistently delivered higher yields, improved resource-use efficiency, and greater economic returns compared to monocropping.

These systems also contribute significantly to soil health by increasing organic carbon content, improving nutrient cycling, and improving soil structure. The inclusion of legumes and other complementary crops further strengthens sustainability through biological nitrogen fixation, reducing dependence on external inputs. Importantly, tuber crop-based systems demonstrate resilience to climatic stresses such as drought and erratic rainfall, ensuring more stable yields under adverse conditions.

From a socio-economic perspective, diversification with tuber crops creates opportunities for income generation, employment, and value addition through processing and industrial uses. Their adaptability to marginal environments makes them particularly valuable for resource-poor farmers, improving livelihood security and reducing production risks.

Despite these advantages, the potential of tropical tuber crops remains underexploited. Continued research, policy support, and technological innovation are essential to unlock their full benefits. Future research should focus on the following areas:

- **Systematic farming systems research:** Develop and evaluate profitable, location-specific tuber crop-based farming models that integrate crops, livestock, and allied enterprises.
- **Sustainable cropping system design:** Optimize combinations involving tuber crops with high-value vegetables, millets, pulses, and oilseeds to maximize productivity and resource efficiency.
- **Integration with specialty crops:** Explore viable systems incorporating seed spices and

medicinal plants alongside tuber crops for diversified income streams.

- **Shade tolerance and plantation compatibility:** Identify and breed high-yielding, shade-tolerant varieties suitable for integration with plantation crops such as coconut, rubber, and arecanut.
- **Below-ground interactions:** Conduct detailed studies on root architecture, allelopathic effects, and synergistic interactions to better understand interspecific dynamics in mixed cropping systems.
- **Agroforestry and perennial systems:** Standardize technologies for cultivating tuber crops under different perennial systems beyond coconut-based models.
- **Socio-economic assessment:** Undertake comprehensive evaluations of adoption, profitability, labour dynamics, gender roles, and market linkages.

Additional insights for future research

To further strengthen the role of tuber crops in cropping systems, future research should also emphasize:

- **Climate-resilient breeding:** Develop drought, heat, and flood tolerant varieties using advanced breeding techniques, including genomics and marker-assisted selection.
- **Biofortification:** Enhance the nutritional quality of tuber crops by increasing micronutrients such as vitamin A, iron, and zinc to combat hidden hunger.
- **Mechanization and precision agriculture:** Design small-scale, affordable machinery for planting, harvesting, and processing, along with digital tools (e.g., remote sensing, AI-based advisory systems) tailored to smallholders.
- **Post-harvest and value chain development:** Improve storage, processing, and transportation systems to reduce losses and expand market opportunities, including export potential.
- **Circular and regenerative approaches:** Integrate tuber crops into regenerative agriculture frameworks, focusing on carbon sequestration, waste recycling, and reduced chemical inputs.
- **Policy and institutional support:** Study policy frameworks that incentivize diversification, ensure price stability, and strengthen farmer-producer organizations.
- **Consumer awareness and market demand:** Promote the nutritional and industrial value of tuber crops to stimulate demand and support market-driven production.

In conclusion, crop diversification through tropical tuber crops offers a sustainable pathway for achieving food and nutritional security, economic stability, and environmental resilience. The validated findings from ICAR-Central Tuber Crops Research Institute provide a solid foundation for scaling these systems across diverse agro-ecological regions, supporting inclusive and climate-resilient agricultural development.

7. Way Forward and Future Research

The future of crop diversification involving tropical tuber crops such as cassava, sweet potato, yam, and taro lies in adopting a holistic, technology-driven, and climate-resilient research approach. As agricultural systems face increasing pressure from climate change, resource degradation, and nutritional challenges, future research must move beyond conventional productivity enhancement toward sustainability, value addition, and system resilience.

i. **Diversified and Integrated Farming Systems:** Research should design location-specific, diversified cropping models integrating tuber crops with cereals, pulses, oilseeds, and livestock. Key areas include intercropping and multi-tier systems, tuber crop-based agroforestry models and integration with livestock and fisheries for circular farming.

ii. **Soil Health and Resource Management:** Sustainable intensification requires improved management of soil and water resources. Future research should include precision nutrient management tailored to tuber crops, organic and conservation agriculture practices, carbon sequestration potential of tuber crop-based systems and efficient irrigation and water-saving technologies in tuber crop-based cropping systems.

iii. **Mechanization and Smart Agriculture:** Labour shortages and rising costs necessitate mechanization. Research priorities include development of machinery for planting, harvesting, and processing of tubers, use of sensors, drones, and AI-based decision support systems and digital agriculture platforms for real-time advisory services.

iv. **Market Linkages and Value Chain Development:** Research should strengthen the economic viability of tuber crops by developing efficient supply chains and market infrastructure, promoting farmer producer organizations (FPOs) and exploring export opportunities and niche markets.

v. **Policy Support and Institutional Framework:** Future research must inform policy decisions by generating evidence on the benefits of diversification, supporting inclusion of tuber crops in food security and nutrition programmes and designing incentives for diversified farming systems.

vi. **Participatory and Farmer-Centric Research:** Greater emphasis should be placed on on-farm trials and participatory breeding, inclusion of indigenous knowledge systems and gender-sensitive and smallholder-focused interventions.

vii. **Interdisciplinary and Systems Approach:** The complexity of diversification demands collaboration across disciplines viz., agronomy, breeding, soil science, economics, and food technology. Systems-based research integrating production, processing, and marketing will be key to long-term success.

The way forward lies in transforming tropical tuber crops from underutilized staples into central components of climate-smart, nutrition-sensitive, and market-oriented farming systems. Future research must bridge gaps between productivity, sustainability, and profitability, ensuring that crop diversification becomes a viable and scalable strategy for resilient agriculture.

8. References

Adekunle, Y.A., Olowe, V. I., Olasantan, F.O., Okeleye, K.A., Adetiloye, P.O. and Odedina, J.N. 2014. Mixture productivity of cassava-based cropping system and food security under humid tropical conditions. *Food and Energy Security,* **3**(1): 46-60.

AICRP. 2006. *Annual Report 2005-2006*, All India Co-ordinated Research Project on Tuber Crops, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India. 128 p.

AICRP. 2010. *Annual Report 2009-2010,* All India Co-ordinated Research Project on Tuber Crops, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India. 139 p.

Aigh, B.F. 2007. The role of tropical legumes in improving soil fertility and crop production. *Plant and Soil Science,* **3**: 224-229.

Ajeigbe, C.M. 2003. Effects of cassava inter-planted with cowpea on potassium status of an alfisol and yield of cassava in the Southwestern Nigeria. *Soil Science,* **5**: 403-408.

Anju, P.S., Susan John, K., Bhadraray, S., Suja, G., Jeena Mathew, Nair, K.M., Sunitha, S. and Veena S.S. 2020. Customized fertilizer formulations for elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) under intercropping in coconut gardens for Kerala, India. *Journal of the Indian Society of Soil Science*, **68**(2): 132-144.

Ayilara, M.S., Abberton, M., Oyatomi, O.A., Odeyemi, O. and Babalola, O.O. 2023. Nutritional properties of underutilized legumes and intercropped maize. *Frontiers in Soil Science*, https://doi.org/10.3389/fsoil.2023.1047847.

Bourke, R.M. and Ramakrishna, A. 2009. Sweet potato in highlands agricultural systems of Papua New Guinea. In: *Soil fertility in Sweet Potato Based Cropping Systems in the Highlands of Papua New Guinea*, Kirchhof, G. (Ed.), ACIAR Technical Reports No **71**, Australian Centre for International Agricultural Research, Canberra, pp. 7-11

Byju, G., Nedunchezhiyan, M., James George, Sunitha, S., Kamalkumaran, R., Singh, P. P., Mamatha, K., Surajit Mitra, Jayanta Tarafdar, Ketan Desai, Ravi, V., Vani, M., Sabitha, S. and Remya Remesh, K.R. 2016. Fertilizer best management practices by SSNM and customized fertilizers for elephant foot yam (*Amorphophallus paeoniifolius)* cultivation in India. *Indian Journal of Agricultural Sciences,* **86** (4): 485-493.

Byju, G., Anupriya, A.S., Suja, G., Jaganathan, D. and Rethinam, P. 2023. Potential of tuber crops for intercropping in oil palm gardens under varied agroclimatic conditions in India. *International Journal of Oil Palm,* **15** (1&2): 46-54.

Byju, G. and Suja, G. 2020. Mineral nutrition of cassava. *Advances in Agronomy*, **159**: 169-235, https://doi.org/10.1016/bs.agron.2019.08.005.

Carsky, R.J. and Toukourou, M.A. 2005. Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. *Nutrient Cycling in Agroecosystem,* **71**: 151-162.

CPCRI. 2011. Annual Report 2010-2011. Central Plantation Crops Research Institute, Kasaragod, Kerala.

CTCRI. 1983. Annual Report 1982-1983. Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, 189 p.

Das, P.K. 1984. *Review Report on Agricultural Economics Research(1980-84)*, Central Plantation Crops Research Institute, Kasargod, India.

Das, P.K. 1991. Coconut intercropping with cassava: An economic analysis. *Coconut Research and Development Journal,* **7**(02), 34. https://doi.org/10.37833/cord.v7i02.248.

Delaquis, E., de Haan, S. and Wyckhuys, K.A.G. 2018. On-farm diversity buffers yield losses from insect pests in smallholder cassava systems. *Agriculture, Ecosystems and Environment,* **256**: 84-93.

Edison, S., Ravindran, C.S. and Suja, G. 2006. Tropical tuber crops: a popular choice as intercrops in coconut plantations. *Indian Coconut Journal*, **37**(3): 2-7.

FAOSTAT. 2023. Food and Agriculture Organization of the United Nations. *FAOSTAT Statistical Database.* https://www.fao.org/faostat/

Farinu, G.E.M. 2006. Effects of intercropping systems involving legumes on soil organic carbon. *Journal of Agricultural Research,* **3**: 111-116.

Giller, K.E. 2001. *Nitrogen Fixation in Tropical Cropping Systems*, 2nd Edition. CAB International, Wallingford.

Ghosh, S.P. 1994. Tuber crop based cropping systems. In: Chadha, K.L. and Nayar, G.G. (Eds.). *Tuber Crops,* Malhotra Publishing House, New Delhi, India, pp. 359-368.

Ghosh, S.P., Nair, G.M., Pillai, N.G., Ramanujam, T., Mohankumar, B. and Lakshmi, K.R. 1987. Growth, productivity and nutrient uptake by cassava in association with four perennial species. *Tropical Agriculture,* **64**: 233-236.

Hgaza, V., Diby, L., Oberson, A. and Tschannen, A., Tie, T., Sangakkara, U.R., Ake, S. and Frossard, E. 2012. Nitrogen use by yam as affected by mineral fertilizer application. *Agronomy Journal*. **104**(6): 1558-1568. 10.2134/agronj2011.0387.

Hidoto, L. and Loha, G. 2013. Effect of intercropping on growth and yield of cassava in southern Ethiopia. *Journal of Plant Breeding and Crop Science*, **5**(10): 186-194.

Howeler, R. 2002. Cassava mineral nutrition and fertilization. In: Hillocks, R.J., Thresh, J.M. and Bellotti, A.C. (Eds.). *Cassava: Biology, Production and Utilization*. pp. 115-147, CAB International, Wallingford.

ICAR-CTCRI. 2018. Annual Report 2017-2018. ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, 189 p.

ICAR-CTCRI. 2019. Annual Report 2018-2019. ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, 189 p.

ICAR-CTCRI. 2020. Annual Report 2019. ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, 186 p.

ICAR-CTCRI. 2023. Annual Report 2022. ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, 179 p.

Ijoyah, M.O. and Aghimien, A.E. 2012b. Performance of cassava (*Manihot esculenta* Crantz)-sweet potato (*Ipomoea batatas* L.) intercrop as influenced by time of planting of sweet potato in Makurdi, Nigeria. *International Journal of Agricultural Research,* **7**(7): 545-553.

Ijoyah, M.O. and Jimba, J. 2012a. Performance of cassava intercropped with egusi melon (*Cucumeropsis mannii* Naudin) in Makurdi, Nigeria. *International Journal of Agricultural Research*, **7**(5): 225-234.

Jacob John, Rani, B., Varughese, K. and Babu Mathew, P. 2013. Performance of cassava, sweet potato and Chinese potato in rice based cropping systems of Southern Kerala. *Journal of Root Crops*, **39**(2): 105-109.

Jata, S.K., Nedunchezhiyan, M., Maity, S.K. and Mallikarjun, M. 2019. Fertigation effects on elephant foot yam (*Amorphophallus paeoniifolius*) + greengram intercropping system.*Indian Journal of Agricultural Sciences*, **89**(12): 2032–2036.

Kasele, I.N., Hahn, S.K., Gupta, C.O. and Vine, P.N. 1984. Effects of shade, nitrogen and potassium on cassava. In:*Tropical Root Crops Production and* Uses *in Africa.* IDRC, Ottawa, Canada. pp. 55-58.

Khasanah, N., Van-Noordwijk, M. and Hairiah, K. 2016. *Intercropping Oil Palm: A Tree-Soil Crop Interactions Model.* ICRAF World Agroforestry Nairobi, Kenya.

Kim, B.T. 2005. Influence of cassava inter-planted with soybean on soil chemical properties and yield of cassava. *Soil and Crop Science,* **4**: 608-613.

Martin, F.W. 1985. Difference among sweet potatoes in response to shading. *Tropical Agriculture* (Trinidad), **62**: 161-65.

Mbah, E.U. 2018. Effect of intercropping systems on cassava (*Manihot esculenta* Crantz) yield in southeastern Nigeria. *Nigerian Agricultural Journal,* **49**(1): 75-83.

Mohandas, C. and Siji, J.V. 2012. Nematode problems in sweet potato and their management. In: Nedunchezhiyan, M. and Byju, G. (Eds.). *Sweet potato*, Global Science Books, Japan, pp. 139-142.

Mohankumar, C.R. and Hrishi, N. 1978. lntercropping systems with cassava in Kerala State. *Proceedings of the International Workshop* on *lntercropping with Cassava*. Trivandrum. pp. 31-34.

Mohankumar, C.R., Nair, G.M., Mandal, R.C. and Prabhakar, M. 1980. Effect of plant population and production of quality planting material in cassava. *Proceedings of the National Seminar on Tuber Crops Production Technology*. TNAU, Coimbatore. pp. 60-61.

Mohankumar, C.R. and Nair, P.G. 1990. Production potential and economics of tuber crop based cropping system for low lands. *Indian Journal of Agronomy,* **35** (1&2): 44-49.

Mohankumar, C.R. and Ravindran, C.S. 1990. Economics of intercropping short-duration legumes and vegetables with cassava. *Journal of Root Crops*, ISRC National Symposium 1990, Special: 120-122.

Mohankumar, C.R., Ravindran, C.S. and Nair, P.G. 1985. Sequential cropping with tuber crops in single cropped rice fields. *Proceedings of the National Symposium on Tropical Tuber Crops,* 27-29 November 1985. Trivandrum.

Muralidharan, A. and Nayar, T.V.R. 1979. Intercropping with tuber crops in arecanut garden. In: Nelliat, E.V. and Bhat, K.S. (Eds.). *Multiple Cropping in Coconut and Arecanut Gardens*. *Technical Bulletin*, Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 24-27.

Murugesan, P. and Sunitha, S. 2018. Cultivating oil palm in multi-tier system. *Indian Horticulture,* **63**(3): 12-13.

Muthukrishnan, C.R. and Thamburaj, S. 1978. Cassava intercropping pattern and management practices at Tamil Nadu Agricultural University, Coimbatore. *Intercropping with Cassava*. *Proceedings of the International Workshop*, Trivandrum, 27 November - 01 December, 1978. pp. 37-41.

Nair, P.K.R. and Balakrishnan, T.K. 1976. Pattern of light interception by canopies in a coconut cacao crop combination. *Indian Journal of Agricultural Sciences*, **46**: 453-462.

Namanji, S., Ssekyewa, C. and Slingerland, M. 2020. *Oil palm intercropping in Uganda - an assessment of farmer practices and potential for expansion.* Tropenbos International, Wageningen, the Netherlands and Ecological Trends Alliance, Kampala, Uganda, 24 p.

Nayar. T. V.R. 1976. Intercropping in young robusta coffee. *Indian Coffee*, **40**:70-74.

Nayar, T.V.R. 1986. Production Potential of Cassava (*Manihot esculenta*) Intercropped in Coconut Gardens. *Ph.D. Thesis*, Kerala Agricultural University, Kerala, India.

Nayar, T.V.R. and Mohankumar, B. 1989. Soil fertility management in cropping systems involving tuber crops. In: *Silver Jubilee Commemoration Volume, 1963-88,* CTCRI, Trivandrum.

Nayar, T.V.R. and Sadanandan, N. 1992. Fertilizer management for cassava intercropped in coconut garden. *Journal of Plantation Crops,* **20**: 135-141.

Nayar, T.V.R. and Suja, G. 1996. Intercropping *Dioscorea* with banana Var. Nendran (Musa, AAB). *Journal of Root Crops,* **22**:115-120.

Nayar, T.V.R. and Suja, G. 1998. Intercropping tubers with banana is remunerative. *Indian Horticulture,* **43** (2):15-17.

Nayar, T.V.R. and Suja, G. 1999. Plant density for intercropping *Dioscorea* in coconut gardens. In: Balagopalan, C., Nayar, T.V.R., Sundaresan, S., Premkumar, T. and Lakshmi, K.R. (Eds.). *Tropical Tuber Crops in Food Security and Nutrition*, Oxford and IBH Publishing Co., Pvt. Ltd. New Delhi. pp. 351-356.

Nayar. T.V.R. and Suja, G. 2000. *Dioscorea* as an intercrop in rubber plantation. *Annual Report* 1998-99, Central Tuber Crop Research Institute, Thiruvananthapuram, Kerala. pp. 42-44.

Nayar, T.V.R., Suja, G. and Byju, G. 2001. Effect of plant density and levels of manuring on productivity of banana-*Dioscorea* intercropping system. *Journal of Root Crops,* **27**(1): 176-180.

Nayar, T.V.R. and Suja, G. 2002. Production potential of tuberous vegetables in association with banana. In: *Abstracts of the International Conference on Vegetables*, 11-14 November 2002, Bangalore, pp. 175-176.

Nayar, T.V.R. and Suja, G. 2004. Production potential of root and tubers in multiple cropping systems involving plantation crops. *Journal of Root Crops,* **30**(2): 93-100.

Nchanji, Y.K., Nkongho, R.N., Mala, W.A. and Levang, P. 2016. Efficacy of oil palm intercropping by smallholder case study in South-West Cameroon. *Agroforestry Systems*, **90**(3): 509-519.

Nedunchezhiyan, M. 2007. Production and energy use efficiency of greater yam (*Dioscorea alata*) based intercropping system as influenced by intercrops and planting patterns. *Indian Journal of Agronomy*, **52**(3): 216-219.

Nedunchezhiyan, M. 2010. Performance of greater yam (*Dioscorea alata*)+maize (*Zea mays*) intercropping as influenced by mulching and levels of N-P-K fertilization. *Indian Journal of Agronomy*, **55**(1): 1-4.

Nedunchezhiyan, M. 2011. Evaluation of sweet potato (*Ipomoea batatas*) based strip intercropping systems for yield, competition indices and nutrient uptake. *Indian Journal of Agronomy*, **56**(2): 98-103.

Nedunchezhiyan, M. 2014. Production potential of intercropping spices in elephant foot yam (*Amorphophallus paeoniifolius*). *Indian Journal of Agronomy,* **59** (4): 596-601.

Nedunchezhiyan, M. and Byju, G. 2005. Productivity potential and economics of elephant foot yam based cropping system. *Journal of Root Crops*, **31**(1): 34-39.

Nedunchezhiyan, M. and Byju, G. 2006. Influence of intercrops on growth and yield of greater yam in different planting systems. *Journal of Root Crops*, **32**(1): 41-46.

Nedunchezhiyan, M., Byju, G. and Mukherjee, A. 2008a. Performance of cassava varieties intercropped in coconut plantation. *Indian Journal of Horticulture*, **65**:122-125.

Nedunchezhiyan, M., Byju, G. and Naskar, S.K. 2006b. Effect of intercrops and planting pattern on incidence of anthracnose, productivity potential and economics of greater yam (*Dioscorea alata*). *The Indian Journal of Agricultural Sciences*, **76**(2): 132-134.

Nedunchezhiyan, M., Byju, G. and Naskar, S.K. 2007. Sweet potato (*Ipomoea batatas* L.) as an intercrop in a coconut plantation: growth, yield and quality. *Journal of Root Crops*, **33** (1): 26-29.

Nedunchezhiyan, M., Byju, G. and Naskar, S.K. 2008b. Performance of sweet potato (*Ipomoea batatas*) varieties under shaded and open field conditions. *Indian Journal of Agricultural Sciences*, **78**(10): 974-977.

Nedunchezhiyan, M., Byju, G. and Naskar, S.K. 2008d. Yield potential and economics of elephant foot yam (*Amorphophallus paeoniifolius*) + green gram (*Vigna radiata*) intercropping system as influenced by mulching and fertilizer levels. *Indian Journal of Agricultural Sciences*, **78**(1): 17-20.

Nedunchezhiyan, M., Byju, G., Naskar, S.K. and Mukherjee, A. 2010c. Effect of mulching and graded doses of fertilizer on yield and nutrient uptake of greater yam + maize intercropping system. *Indian Journal of Horticulture,* **67**(special issue): 283-287.

Nedunchezhiyan, M., Byju, G. and Ravi, V. 2012a. Photosynthesis, dry matter production and partitioning in cassava (*Manihot esculenta* Crantz) under partial shade of a coconut plantation. *Journal of Root Crops*, **38**: 116-125.

Nedunchezhiyan, M., Byju, G., Naskar, S.K. and Edison, S. 2008c. *Greater Yam Based Cropping*

System: Resource Utilization and Management.Technical Bulletin Series No. **49**. Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India, 43 p.

Nedunchezhiyan, M., Jata, S.K. and Byju, G. 2012b. Sweet potato based cropping systems. In: Nedunchezhiyan, M. and Byju, G. (Eds.). *Sweet potato*, Global Science Books, Japan, pp. 11-16.

Nedunchezhiyan, M., Jata, S.K., Dixit, J., Chauhan, V.B.S., Gowda, K.H. and Pati, K. 2024. Evaluation of taro (*Colocasia esculenta*)-based cropping system for crop diversification under rainfed upland ecosystem of eastern India. *Current Horticulture*, **12**(3): 34-39. DOI: 10.48165/chr.2024.12.3.04.

Nedunchezhiyan, M., Kumar, S.J. and Sahoo, B. 2021a. Effect of weed control on growth, dry-matter production and partitioning in elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson]. *Current Horticulture*, **9**(1): 40-44.

Nedunchezhiyan, M., Laxminarayana, K., Rajasekhara Rao, K. and Satapathy B.S. 2011a. Sweet potato (*Ipomoea batatas* L.) based strip intercropping: I. Interspecific interactions and yield advantage. *Acta Hungaria,* **4**: 1-12.

Nedunchezhiyan, M., Misra, R.S. and Naskar, S.K. 2011b. Zero tillage stand establishment of sweet potato: An option for intensive rice based cropping system. In: *Proceedings of National Seminar on Climate Change and Food Security: Challenges and Opportunities for Tuber Crops*, Indian Society for Root Crops, Central Tuber Crops Research Institute, Thiruvananthapuram, pp. 256-260.

Nedunchezhiyan, M., Misra, R.S. and Shivalingaswamy, T.M. 2002. Elephant foot yam (*Amorphophallus paeoniifolius* (D.) Nicolson) as an intercrop in banana and papaya. *The Orissa Journal of Horticulture*, **30**(1): 80-82.

Nedunchezhiyan, M., Pati, K., Chauhan, V.B.S., Gowda, K.H., Arutselvan, R., Jata, S.K. and Dixit, J. 2021b. Taro (*Colocasia esculenta* Schott.) based intercropping systems: Interspecies interaction effects on growth and yield. *Journal of Root Crops*, **47**(1 & 2), 69-74.

Nedunchezhiyan, M., Rajasekhara Rao, K., Laxminarayana, K. and Satapathy, B.S. 2010b. Effect of strip cropping involving sweet potato (*Ipomoea batatas* L.) on soil moisture conservation, weevil infestation and crop productivity. *Journal of Root Crops*, **36**(1): 53-58.

Nedunchezhiyan, M., Rajasekhara Rao, K, and Satapathy, B.S. 2010a. Productivity potential, biological efficiency and economics of sweet potato (*Ipomoea batatas*)–based strip intercropping systems in rainfed Alfisols. *Indian Journal of Agricultural Sciences*, **80**(4): 327-330.

Nedunchezhiyan, M., Sinhababu, D.P., Sahu, P.K. and Pandey, V. 2013. Growth and yield of sweet potato (*Ipomoea batatas* L.) in rice fallows: Effect of tillage and varieties. *Journal of Root Crops*, **39**(2): 110-116.

Nedunchezhiyan, M., Sivakumar, P.S., Naskar, S.K. and Misra, R.S. 2006a. Sweet potato: A suitable crop for rice based cropping system. In: Naskar, S.K., Nedunchezhiyan, M., Rajasekhara Rao, K., Sivakumar, P.S., Ray, R.C., Misra, R.S., Mukherjee, A. (Eds.). *Root and Tuber Crops: In Nutrition, Food Security and Sustainable Environment,* Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, pp. 135-138.

Nedunchezhiyan, M., Suja, G. and Ravi, V., 2022. Tropical root and tuber crops based cropping systems – a review. *Current Horticulture*, **10**(1); 14-22.

Nelliat, E.V. 1979. Prospects of multiple cropping. In: Nelliat, E.V. and Bhat, K.S. (Eds.). *Multiple Cropping in Coconut and Arecanut Gardens*. *Technical Bulletin* **3**, Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp.3-5.

Nelliat, E.V., Bavappa, K.V.A. and Nair, P.K.R. 1974. Multistoreyed cropping. A new dimension in multiple cropping for coconut plantation. *World Crops,* **26**: 262-266.

Nelliat, E.V. and Bhat, K.S. 1979. *Multiple Cropping in Coconut and Arecanut Gardens. Technical Bulletin* **3**, CPCRI, Kasargod, India. 53 p.

Njoku, D.N. and Muoneke, C.O. 2008. Effect of cowpea planting density on growth, yield and productivity of component crops in cowpea/cassava intercropping system.*Journal of Tropical Agriculture, Food, Environment and Extension*, **7**(2): 106-113.

Njoku, S.C., Muoneke, C.O., Okpara, D.A. and Agbo, F.M.O. 2007. Effect of intercropping varieties of sweet potato and okra in an Ultisol of south eastern Nigeria. *African Journal of Biotechnology*, **6**(14): 1650-1654.

Njukwe, E., Night, G., Okechukwu, R.U., et al. 2011. *Cassava pests and diseases and their management in Rwanda: role of intercropping systems*. IITA/CIAT Eastern Africa Cassava Program Report, International Institute of Tropical Agriculture, Ibadan, Nigeria, pp. 1-18.

Norman, D.W. 1974. Rationalising mixed cropping under indigenous conditions: the example of Northern Nigeria. *The Journal of Development Studies*, **11**(1): 3-21.

Nuertey, B.N. 2000. Studies into Oil Palm-Based Cropping Systems in Ghana. *Ph. D. Thesis*. Doctor of Philosophy in Crop Science, University of Ghana, Accra, Ghana, 77 p.

Nwokoro, C.C., Kreye, C., Necpalova, M., Adeyemi, O., Busari, M., Tariku, M., Tokula, M., Olowokere, F., Pypers, P., Hauser, S. and Six, J. 2021. Developing recommendations for increased productivity in cassava-maize intercropping systems in Southern Nigeria. *Field Crops Research,* **272**:108283. doi: 10.1016/j.fcr.2021.108283.

Ogola, J.B.O. et al. 2013. Cassava-legume intercropping effects on yield and soil fertility in Kenya. *African Crop Science Journal*, **21**(2): 123-134.

Prabhakar, M., Mohankumar, C.R. and Nair, G.M. 1983. Intercropping vegetables with cassava. *Journal of Root Crops,* **9**(1-2): 21-26.

Prabhakar, M., Nair, G.M. and Ghosh, S.P. 1984. lntercropping legumes with cassava (unpublished).

Prabhakar, M. and Pillai, N.G. 1984. Multiple cropping systems with tuber crops. *Indian Farming,* **33**: 25-28.

Pushpakumari, R. and Sasidhar, V.K. 1992. Fertilizer management of yams and aroids in coconut based cropping system. *Journal of Root Crops,* **18***:* 99-102.

Ramachandrudu, K., Arulraj, S. and Rao, B.N. 2013. Scope for intercropping in grown-up oil palm gardens. http://www.krishisewa.com/articles/production-technology/309-intercropping-oil-palm-gardens.html (Accessed: October 2016).

Ramanujam, T., Indira, P. and Nair, G.M. 1984. Productivity of cassava under shade. *Indian Farming,* **33** (12): 39-40.

Ravi, V., Suja, G., Saravanan, R. and Sanket J. More. 2021. Advances in cassava-based multiple-cropping systems. In: Warrington, I. (Ed.). *Horticultural Reviews*.Volume **48**, 1st Ed. John Wiley & Sons, Inc.pp. 153-232.

Ravindran, C.S. 1997. Nutrient - Moisture - Light Interactions in a Coconut Based Homestead Cropping System, *Ph.D. Thesis*, Kerala Agricultural University, Kerala, India.

Ravindran, C.S. and Kabeerathumma, S. 1991. Intercropping in *Amorphophallus* under shaded condition. *Journal of Root Crops*, ISRC National Symposium, 1990, **17** Special Issue: 112-115.

Ravindran, C.S., Ramanathan, S. and Easwaran, M. 2013. Agro-techniques of Tuber Crops. *Booklet*, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India. 32 p.

Sannamarappa, M. and Muralidharan, A. 1982. In: Bavappa, K.V.A., Nair, M.K. and Premkumar, T. (Eds.). *The Arecanut Palm* (*Areca catechu* Lim.). Central Plantation Crops Research Institute, Kasaragod 670124, Kerala, India, pp. 133-149.

Slingerland, M.A., Khasanah, N.M., van Noordwijk, M., Susanti, A. and Meilantina, M. 2019. Improving smallholder inclusivity through integrating oil palm with crops. In: *Exploring Inclusive Palm Oil Production*, ETFRN and Tropenbos International, Wageningen, pp.147-154.

Sparnaaij, L.D. 1957. Mixed cropping in oil palm cultivation. *Journal of the West African Institute for Oil Palm Research,* **2**(7): 244-264.

Suboh, I., Norkaspi, K. and Raja Zulkifli, R.O. 2009. Double-row avenue system for crop integration with oil palm. *MPOB Information Series*, **465**(424): 1-4.

Suja, G. 2001. Resource Management for Intercropping White Yam (*Dioscorea rotundata* Poir.) in Coconut Garden. *Ph.D. Thesis*, Kerala Agricultural University, Kerala, India.

Suja, G. 2005. Impact of nutrient management on biomass production and growth indices of white yam (*Dioscorea rotundata* Poir.) intercropped in a coconut plantation in South India. *Tropical Agriculture,* **82** (3): 173-182.

Suja, G., Jaganathan, D., Sheela, M.N., Sajeev, M.S., Makeshkumar, T. and Harish, E.R. 2023. *Cassava*, Technical Bulletin No. **93**, ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, 74 p.

Suja, G., Nair, V.M., Saraswathy, P. and Geethakumari, V.L. 2003a. Influence of growth-promoting substances on sprouting of white yam (*Dioscorea rotundata)* setts. *Tropical Science,* **43** (4): 170-173.

Suja, G., Nair, V.M., Saraswathy, P. and Nayar, T.V.R. 2004. Response of white yam intercropped in coconut garden to organic manures, nitrogen and potassium. *Journal of Plantation Crops,* **32** (2): 21-27.

Suja, G., Nair, V.M., Saraswathy, P. and Pushpakumari, R. 2003b. Plant population and sett size effects on white yam (*Dioscorea rotundata* Poir.) intercropped in coconut garden. *Tropical Agriculture*, **80** (3): 157-162.

Suja, G. and Nayar, T.V.R. 2005. Effect of plant density and mulching on growth and yield of arrowroot (*Maranta arundinacea* L.). *Madras Agricultural Journal*, **92**(1-3): 149-153.

Suja, G., Nayar, T.V.R. and Ravindran, C.S. 2003c. Influence of agronomic practices on starch yield of arrowroot (*Maranta arundinacea* L.). *Journal of Root Crops,* **29**(2): 49-52.

Suja, G., Nayar, T.V.R. and Ravindran, C.S. 2006. Influence of nutrient management in arrowroot (*Maranta arundinacea* L.) on biomass production, nutrient uptake and soil nutrient status. *Journal of Root Crops*, **32**(2): 162-165.

Suja, G. and Nedunchezhiyan, M. 2018. Crop diversification with tropical tuber crops for food and livelihood security. *Journal of Root Crops,* **44**(1): 3-11.

Suja, G., Ravindran, C.S. and Jaganathan, D. 2021. *Best Agronomic Practices for Arrowroot*, *Technical Bulletin Series* No. **85**, ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, 36 p.

Suja G., Saravanan, S. and Sreekumar J. 2025a. Evaluation of intercropping elephant foot yam (*Amorphophallus paeoniifolius*) with pulses for yield, economics, corm quality and soil health. *Current Horticulture,* **13**(2): 48-54.

Suja, G. and Sreekumar, J. 2015. Crop diversification with short-duration cassava (*Manihot esculenta*) in the humid tropics for agronomic and economic benefits.*Indian Journal of Agricultural Sciences,* **85**(12):1619-1625.

Suja G., Sreekumar J., Sunitha S. and Jacob John. 2025b. Evaluation of short-duration cassava (*Manihot esculenta* Crantz) cropping system for profitability, energy efficiency and soil restoration. *Current Horticulture,* **13**(1): 35-41.

Suja G., Sreekumar J., Sunitha S. and Jacob John. 2025c. Rice – cassava + pulse system for productivity, profitability and energy efficiency. *Annals of Agricultural Research,* **46**(1): 1-7.

Suja, G., Sreekumar, J., Sunitha, S.and John, J. 2025d. Growth dynamics, yield and quality of short-duration cassava in rice-based cropping systems, *Journal of Horticultural Sciences*, **20**(2), https://doi.org/10.24154/jhs.v20i2.2819.

Suja, G., Susan John, K. and Sreekumar, J. 2010b. Soil test based nutrient management for short-duration cassava (*Manihot esculenta*). Analysis of growth, biomass, yield, quality, nutrient uptake and soil nutrient status. *Indian Journal of Agronomy,* **55**(4): 66-72.

Suja, G., Susan John, K. and Sreekumar, J. 2011. Impact of nutrient management based on soil test data on biomass production and partitioning and growth indices of short-duration cassava (*Manihot esculenta* Crantz). *Indian Journal of Agricultural Science*s, **81**(3): 247–251.

Suja, G., Susan John, K., Sreekumar, J. and Srinivas, T. 2010a. Short-duration cassava genotypes for crop diversification in the humid tropics: Growth dynamics, biomass, yield and quality. *Journal of the Science of Food and Agriculture,* **90**: 188-198.

Suma, A., Raju, V.K., Sujatha, V.S., Nybe, E.V. and Estelitta, S. 1990. Cassava-A potential intercrop for banana. Paper presented at the *National Symposium on Recent Advances in the Production and*

Utilization of Tropical Tuber Crops. 7-9 November 1990, Trivandrum.

TNAU. 2020. Crop Production Guide: Package of Practices - Tuber Crops. Tamil Nadu Agricultural University, Coimbatore, India.

Zara, D.L., Cuevans, S.E. and Carlos, J.T. 1982. Performance of sweet potato grown under coconuts. In: Villareal, R.L. and Griggs, T.D. (Eds.). *Sweet Potato,* AVRDC, Taiwan. pp. 233-242.

Zou, Y.N., Srivastava, A.K., Wu, Q.S. and Huang, Y.M. 2020. Arbuscular mycorrhizal fungi and intercropping effects on citrus root colonization and nutrient uptake. *Applied Soil Ecology*,**147**, 103364.https://doi.org/10.1016/j.apsoil.2019.103364.

Tuber crops for.....

Food, Health, Wealth and Prosperity

भाकृअनुप
ICAR

ICAR-Central Tuber Crops Research Institute

Sreekariyam, Thiruvananthapuram 695 017, Keralam, India

Phone: (91) (471) 2598551 to 2598554

E-mail: director.ctcri@icar.org.in

Website: https://www.ctcri.org

Social Media

Facebook Twitter Whatsapp Instagram You Tube