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Resilient and regenerative agro-technologies of tuber crops for a sustainable future

Tropical tuber crops like cassava, sweet potato, yams, edible aroids such as elephant foot yam, taro and tannia are food cum nutritional cum livelihood security crops that are decisive components in agri-food systems. It is imperative to enhance food production under changing climatic scenarios, along with sustainable resource management. This document provides an overview of crop production technologies for tuber crops aimed at promoting productive, profitable and environmentally conserving farming. Resilient cropping systems and IFS models, sustainable soil fertility management with emphasis on nutrient use efficient varieties, integrated nutrient management, site specific nutrient management, customized fertilizers, micronutrient formulations, organic management, precision nutrient and water management, including smart farming, climate resilient technologies and certain novel initiatives in this direction are discussed.

Keywords: ICAR-CRCRI, IFS models, Micronutrient formulations, Sustainable soil fertility management.

ROOT and tuber crops like cassava, sweet potato, yams, and edible aroids, including elephant foot yam, taro, and tannia play a vital role as staple foods in many developing regions. In India, where approximately 45% of the population relies exclusively on agriculture, the sector faces significant challenges due to increasing climate variability. To meet the Sustainable Development Goal of zero hunger by 2030, it is imperative to enhance agricultural output, while preserving natural resources and maintaining ecosystem balance. Resilient and regenerative agricultural practices are key to building a sustainable agri-food future. Crop production technologies for tuber crops aimed at promoting efficient, profitable, competitive, and environmentally sustainable farming are discussed.

SUSTAINABLE CROPPING SYSTEMS AND IFS MODELS FOR CLIMATE RESILIENT AGRICULTURE

Tuber crops with plantation crops/fruit crops/ trees

Tropical tuber crops like cassava, greater yam, lesser yam, elephant foot yam, tannia, and arrowroot can be cultivated under plantation crops (coconut, arecanut, coffee, rubber) and fruit crops (banana, mango, litchi) as they thrive in similar ecological conditions. Elephant foot yam and arrowroot are highly compatible in coconut and arecanut gardens. Growing elephant foot yam, greater yam, and white yam in the interspaces of banana (*Nendran* and *Robusta*) is productive and profitable, saving 50% FYM, N, and P. Such systems combine cash income from the main crop with food and fodder from tuber intercrops, act as insurance against natural calamities, improve resource use efficiency, ensure food security, enhance employment, and augment net farm income.

Tuber crops with cereals, vegetables, pulses and oilseeds

Short-duration pulses and vegetables are suitable intercrops in tuber crops. In South India, cassava intercropping with legumes (groundnut, cowpea, black gram) and vegetables (French bean, onion, coriander) is feasible. Sweet potato + red gram strip intercropping (1:1) performs well in upland

Coconut + cassava

Coconut + elephant foot yam

Coconut + greater yam

Coconut + dwarf white yam

Coconut + arrowroot

Coconut + tannia

Coconut based cropping systems

Banana + white yam

Banana + dwarf white yam

Banana + elephant foot yam

Banana based cropping systems

ecosystems. Greater yam + maize reduces anthracnose incidence by 60%, increases yam yield by 26.3% (17.3 t/ha), produces 1425 kg/ha maize, and provides additional income of ₹22,055/ha. Taro + vegetable cowpea (1:1) is highly efficient with cormel equivalent yield of 19.48 t/ha, LER >1, net returns of ₹1,69,700/ha, and B:C ratio of 2.38. Elephant foot yam + green gram improves soil quality and income. Other viable models include taro + maize and taro + pigeonpea (5:1 replacement).

Cassava, sweet potato, elephant foot yam, and taro can be raised as sequential crops in rice fallows. Sweet potato establishes well under zero tillage after rice harvest. Short-duration cassava varieties (*Sree Vijaya, Sree Jaya, Vellayani Hraswa, Kalpaka*) are suitable for rice-based intensification. Sequential cropping of vegetable cowpea with short-duration cassava saves nutrients and increases income. Profitable models include rice-black gram-short-duration cassava, rice-short-duration cassava + black gram, elephant foot yam + soybean, taro + green gram, dwarf white yam + green gram, and rice-cassava + cluster bean. Nutrient savings include 50% FYM, 50% N, and 100% P. Socio-economic analysis revealed that integrating tuber crops with coconut, arecanut, banana, and rubber gives 10–12 t/ha additional yield, ₹1.0–1.25 lakhs additional

Cropping systems involving short-duration cassava and pulse crops in rice based systems

Elephant foot yam + pulse crops

Taro + pulse crops

Dwarf white yam + pulse crops

Dwarf white yam after pulse crop harvest

Rice-cassava + cluster bean

Greater yam + maize

Sustainable cropping systems models

profit, and 150-200 mandays/ha employment, ensuring system sustainability. Profits from models were: rice-black gram-cassava (₹95,759/ha), rice-cassava + black gram (₹61,737/ha), elephant foot yam + soybean (₹2,33,164/ha), taro + green gram (₹2,21,452/ha), dwarf white yam + green gram (₹1,83,842/ha), and rice-cassava + cluster bean (₹97,740/ha).

Integrated farming system model

An integrated organic farming model (IOFS) (75 cents) involving tuber crops and animal component can include cassava + vegetable cowpea/amaranthus (7%), banana + elephant foot yam (13%), taro + maize (13%), vegetables-pulses (20%), vegetables-oilseeds (7%), pineapple/moringa/*agathi* as hedges (13%), hybrid napier (7%), dairy (8 cows and 3 calves, 13%), and lemongrass/vermicompost units. This system can yield a marketable equivalent yield (MEY) of 22.67 t and net returns of ₹1,16,538, ensuring food, fodder, and income security.

Cassava + amaranthus

Vegetable cowpea

Banana + cucumber

Hedge rows of pineapple, agathi & moringa

General view of IOFS

Dairy unit

Hybrid napier fodder grass

Vermicompost unit

Field view of IOFS

NUTRIENT MANAGEMENT

Nutrient use efficient genotypes

The first K efficient cassava variety *Sree Pavithra* requires only 50% recommended K. Two NPK efficient genotypes CI-905 and 7 III E3-5 (released as *Sree Annam* and *Sree Manna*) yield well at 25% NPK, saving 75%. Sweet potato varieties (*Sree Bhadra, Kishan, Samrat, Kanjangad, Sankar,* 912, *Megh*-II) are N efficient based on nutrient recovery and utilization efficiency.

Wealth from waste

Thippi compost, an organic manure from cassava starch factory waste using earthworms, has high nutrient content and low C:N ratio (8:1). Nutrient composition: N 1.32, P 3.82, K 0.40, Ca 2.18, Mg 0.96, Fe 1.11, Mn 0.08%, Cu 11.23 ppm, Zn 89.93 ppm, several times higher

Sree Pavithra

Sree Manna

Sree Annam

than raw *thippi. Thippi* compost can substitute FYM, green manring, crop residues, vermicompost, coirpith compost and meet 50% NPK plus MgSO4 (2.5 kg/ha) and ZnSO4 (2.5 kg/ha).

Low input management

Using NUE varieties (*Sree Pavithra*, CI-905, CI-906) with integrated nutrient management (cowpea green manure + soil test-based NPK, Mg, Zn, B + biofertilizer consortium) can enhance yield (34 t/ha) in cassava production with B:C ratio of 4.5. Nutrient savings: 100% P, 11.5% K, 62.5% Mg, 80% Zn. Input cost reduction under low-input practices is 55%.

Integrated nutrient management

Cassava: Biofertilizers (*Azospirillum* + Phosphobacterium) + FYM 12.5 t/ha + NPK (50:25:100 kg/ha) saves 50% N and P with comparable yields. Elephant foot yam: biofertilizers (Bacillus cereus, B. megaterium, B. subtilis) reduce chemical fertilizer use. Sweet potato (var. *Bhu Sona*): FYM 5 t/ha + NPK (75:25:75 kg/ha) sustains production and soil quality for 3 years. Packages comprising liming material, soil and foliar application of Ca, Mg, Zn and B can improve yield in sweet potato and elephant foot yam.

CUTTING-EDGE INNOVATIONS BY SSNM

Site Specific Nutrient Management (SSNM) improves nutrient efficiency, fetches high profit and prevents losses using 4R stewardship. Fertilizer best management practices (FBMP) have been standardized for cassava, sweet potato, yams, elephant foot yam, taro, and Chinese potato.

Customized fertilizers and micronutrient formulations

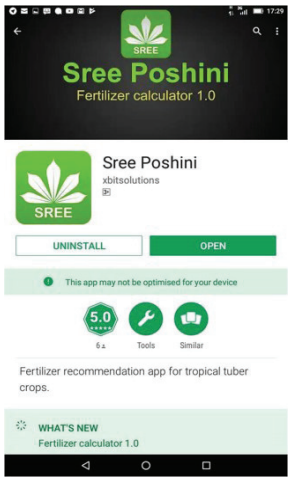
Technology for preparation of customized plant nutrient formulations and micronutrient formulations have been developed. Zone-specific secondary and micronutrient inclusive customized fertilizers are available for cassava, sweet potato, yams, elephant foot yam, taro and Chinese potato. Six designer foliar liquid micronutrient formulations for cassava (acid neutral to alkaline soils), sweet potato, elephant foot yam, yam and Chinese potato have been commercialized in the name "Micronol". Ten Decision Support Systems (DSS) are also available.

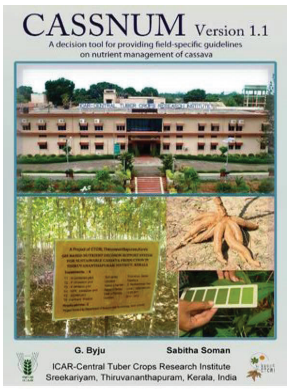
CASSNUM 1.1: Nutrient decision support system

CASSNUM, developed by ICAR-CTCRI, provides SSNM recommendations for cassava and is available online (www.ctcri.in). A newer version of the NuDSS, CASSNUM version 1.1 is available in a CD and is distributed among farmers and extension personnel in India.

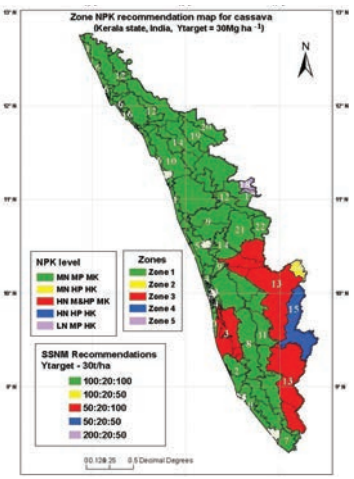
Sree Poshini (Mobile app)

Sree Poshini is a farmer-friendly mobile app available on Google Playstore for SSNM-based fertilizer recommendations in cassava and other tuber crops.





Decision Support System for site specific nutrient management of cassava



GREEN SOLUTIONS FOR CROP MANAGEMENT

Organic production packages for seven tuber crops emphasize seed treatment (cow dung, neem cake, bioinoculants), FYM incubated with bioinoculants, green manures, neem cake and biofertilizers. CMD-resistant cassava variety *Sree Reksha* showed stable yield (34 t/ha) and high profit (₹4,86,456/ha) under organic farming. Organic management resulted in 10-20% higher yield, was equally stable as conventional with 20-40% higher profit. On-farm trials (102 numbers) confirmed the superiority of organic management over existing PoP by yielding 30-35% higher.

Quality improvements included higher dry matter (+2-7%), starch (+4-13%), crude protein (+6-12%), K (+2-10%), Ca (+6-26%), Mg (+3-41%), and reduced anti-nutritional factors. Significantly higher soil quality index in organic system was mostly driven by pH (+0.46–1.20), water holding capacity (+8–28%), SOM (+14–40%), and dehydrogenase activity. Organic systems showed greater energy efficiency.

Glimpses of experiments on organic farming

Use of *beejamrit, panchagavya, vermiwash, ghanjeevamrit, jeevamrit* and cow urine can reduce the organic inputs by 25-50%. Nature positive practices for tuber crop-based systems viz., cassava-groundnut, cassava-cowpea, cassava+cluster bean/chilli, elephant foot yam+cucumber/amaranthus, are also in the frontier. The essential components of these packages for cropping systems comprised farmyard manure, poultry manure, green manure, ash, neem cake, groundnut cake, vermicompost and PGPR

Precision nutrient and water management technologies

Drip irrigation schedules: Irrigation at 100% CPE is critical in all these crops. In elephant foot yam, irrigation at corm development (13–24 weeks) stage is crucial. At Bhubaneswar, drip irrigation at 80% CPE increased elephant foot yam and greater yam yield by 27% over flood irrigation and saved 431 mm water/ha (allowing irrigation of 1.98 ha extra). Daily water requirement (mm/day): cassava 2.7-3.0, sweet potato 2.6–3.0, taro 3.0–3.3, elephant foot yam 4.3–4.5. Water productivity (kg/m^3): cassava 8-9, sweet potato 9-10, taro 3-4, elephant foot yam 4-5.

Fertigation schedules: Short-duration cassava: 50% N & K2O (45–60 DAP), 30% (60–90 DAP), 20% (120 DAP). Normal duration cassava: 50% (90 DAP), 30% (90-120), 20% (150 DAP). Taro: 60:25:75 kg/ha NPK: 50% (within 90 DAP), 25% (90–120), 25% (120–150), saving 25% N & K, with 83% higher yield over soil application. Elephant foot yam: fertigation at 3–4 day intervals in 40–50 splits increases fertilizer use efficiency by 33%. Greater yam: fertigation @ 140:90:140 kg/ha NPK in 60 splits enhances yield, net income, and B:C ratio. In yam + maize system, fertigation increases maize yield by 12% and yam by 18.4%.

Water saving techniques: In elephant foot yam, mulching with ground cover mat or starch-based polymer increases yield (38.4 and 37.2 t/ha), saves 50% water, and improves energy efficiency (24–28%). In taro, irrigation at 50% CPE + ground cover mat enhances yield by 32% over 100% irrigation.

e-Crop based smart farming: ICAR-CTCRI's e-Crop IoT device integrates weather and soil sensors to simulate crop growth and provide real-time advisories (fertilizer, irrigation, pests, diseases and yield predictions) via SMS for smart farming. Demonstrations showed yield increases: sweet potato 220%, cassava 206%, elephant foot yam 163%, banana 215% under smart farming compared to traditional farming. Yield gaps reduced from 50–60% to 5–8% (cassava/sweet potato). N, P, K fertilizer use dropped to 49%, 73%, 57% of traditional levels.

Comparison of yield under traditional farming and eCBSF in cassava and banana

e-Crop based smart fertigation system (eCBSFS): An automated fertigation unit linked to e-Crop, delivering daily NPK and water requirements via SMS advisories, reduces input cost, improves yields and addresses labor/fertilizer shortages.

e-Crop based smart fertigation system

Climate resilient technologies

Cassava varieties, *Sree Reksha* and *Sree Vijaya*, and sweet potato varieties Bhu Krishna and CO-3, show drought tolerance. *Sree Apoorva* and *Sree Swarna* tolerate waterlogging with higher osmolyte levels and antioxidant activity. Foliar KNO3 (1%) at 3–5 MAP improves cassava yield under drought. Heat stress tolerance was achieved with benzyl adenine (1,000 ppm) in cassava and CaCl2 (0.2%) in sweet potato. Climate-smart agriculture (CSA) practices in cassava improves yield (29.5 vs 25.4 t/ha) and reduces GWP (194 vs 272 kg CE/ha) over conventional agriculture. Models (WOFOST, ECOCROP, MaxEnt, CROPWAT, Aquacrop) predicted tuber crop suitability in 2030, 2050, and 2070, confirming tuber crops' climate resilience.

Recent novel techniques

- Protected cultivation protocol for clean seed sweet potato.
- Hydroponic nutrient formulation for sweet potato (patent filed).
- Yam propagation via 20 g minisetts in soil:FYM:cocopeat (1:1:1) or using two-node vine cuttings.
- Elephant foot yam fumigation with carbon disulphide (80 ml/100 kg seed corms) for higher sprouting (99%), yield (+38%), and income (+27%).
- Polybag cultivation of sweet potato using soil:vermicompost:perlite (1:1:1) + 70:37.5:70 NPK/ha for urban farming.

CONCLUSION

Over six decades, tuber crop production technologies have evolved from chemical-intensive practices to resource-efficient, resilient systems. Emphasis is now on diversification, minimal chemical use, biological solutions, and precision-based management. Climate-smart agriculture, integrated farming, and e-Crop-based smart farming are essential for sustainable and resilient tuber crop production.

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