

COMBINED APPLICATION OF MICRONUTRIENTS AND STAKE DIPPING OF CASSAVA FOR ALLEVIATING THE DEFICIENCY AND MAXIMIZATION OF TUBER YIELD

M. Velmurugan^{1*}, S. Manickam¹, L. Pugalendhi¹, T. Krishna Kumar², G. Byju², M. Anand¹, P. R. Kamalkumaran¹, V. Ravichandran¹, T. S. Prabhakaran³, E. Prasanna⁴, and Shaik Sumera¹

¹Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

²ICAR, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

³Centre for Planetary Health and Food Security, Griffith University, Queensland, Australia

⁴University of Pittsburgh, Pittsburgh, PA, USA

*Corresponding author's email: velmurugan.m@tnau.ac.in

ABSTRACT

Cassava is one among the important tuber crop cultivated globally which requires heavy application of organic manures, fertilizers and micronutrients. Cassava is severely prone to micro nutrient deficiencies, more especially the iron induce chlorosis which is noticed invariably in all the soil types. The plants died due to acute micronutrient deficiency causing the drastic crop loss. Considering the acute need of cassava growers, this experiment was conducted over three seasons to determine the effect of combined application of micronutrients and stake dipping for improving the yield of cassava tubers and starch content. The experiment was layout in Randomized Complete Block Design (RCBD), with eight treatments repeated three times in plot size of 4.5x4.5 m for three seasons and between 2022 and 2024, the best treatment was validated through large scale demonstrations in farmers field. The recommended dose of NPK was applied three months after planting and the micronutrients *viz.*, borax, magnesium sulphate and zinc sulphate were applied between one and two months after planting. In addition to the above, dipping the setts (stakes) in ferrous sulphate solution for a period of fifteen minutes before planting and subsequently three to four times of foliar application with 0.5% Ferrous sulphate solution at an interval of weeks times and also on visualization of the deficiency symptoms. The experimental results revealed that the number of tubers (9.53), longest tuber (35.05 cm), maximum tuber girth (19.37), tuber yield (3.42 kg plant⁻¹), starch content of tubers (24.60%) and maximum BC ratio (3.66) were recorded in RCP + dipping the setts (stakes) in 0.5% of FeSO₄ solution + combined application of micronutrients in soil: MgSO₄ (20 kilograms per hectare) + ZnSO₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T₇). The highest tuber dry weight (0.729 kg plant⁻¹) was recorded in the same treatment. This treatment did not produce any micronutrient deficient plants and found to be highly economical to the cassava growers. However, the differential application of micronutrients did not influenced the HCN content of tubers.

Keywords: Cassava, micro nutrient, stake dipping, starch content, tuber yield

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INTRODUCTION

Globally cassava is known as *Manihot esculenta* which is widely and commercially cultivated in tropical and sub-tropical continents as annual crop rather than its perennial nature. This is one of the significant tuber crop cultivated for its starchy tuberous roots. In the tropical regions, the highest order of available carbohydrate for dietary needs is rice, maize and cassava. Cassava is a major food item for more than 500 billion people in developing nations who rely on it for their elementary diet and nourishments. Worldwide, Nigeria is considered as the leader in the production of cassava while Thailand

is the world's largest exporter of cassava starch. Nigeria, Tanzania and Democratic Republic of Congo contributes to 70% of cassava production in Africa with overall contribution of worlds half of the production. Millions of African farmers mainly depend on cassava as a sustainable source of income and it is a vital component of the African diet and recognized as 'complete crop'. Cassava is drought tolerant crop and climate resilient root and tuber crop that has the potential to thrive better under adverse environmental conditions without much crop loss or damage due to their low water requirement. When compared to other food crops of staple in nature, cassava can produce significantly yields higher calories unit area

¹. One third cassava production in tropics is utilized as animal feed in the form of chips and pellets for livestock and poultry.

The starch derived from the tubers possesses multifarious usage as raw material for many industries in various forms for sizing the yarn, finishing of cloth, paper and food industries. In addition to the above, Cassava flour is used in different forms like sago, dextrin, glucose, core binder, alcohol etc. Frozen cassava is being exported from Kochi and Thiruvananthapuram airports of India to many of the Middle Eastern and Gulf countries including Dubai, Kuwait and Qatar to satisfy the demand of the expatriate Indian populations. Across the globe, India is ranking first in cassava productivity, of which Tamil Nadu holds 83.75% of production followed by Kerala (8.74%) and Andhra Pradesh (3.55%) (National Horticulture Board, 2022). Owing to its versatile adaptability and low maintenance operations, this crop cultivation occupies prime position among the growers due the sustained income or the revenue. The cost of cultivation pertinent to the intercultural operations and plant protection measures are meager when compared to other horticultural crops. As futuristic development, the amendment on National Policy on Biofuels (Gazette notification of India, 2022) and as well as Ethanol Blended Petrol (EBP) can be achieved through the starch rich materials including cassava.

The tuber yield of cassava is determined by judicious application of nutrients (Howeler, 2002, Howeler, 2011, Suganya *et al.*, 2020 and Janket *et al.*, 2021). Cassava is ready for harvesting after nine to ten months after planting. Being a tuber crop, it needs a heavy application of organic manures, fertilizers and micronutrients Rolinda *et al.* (2008) and highly prone to micro nutrient deficiencies, more especially the iron induced chlorosis is noticed invariably in all the soil types. Later, the plants died due to acute micronutrient deficiency symptoms. The blades of the budding and fully opened leaf are mostly damaged and it indicates the crop requirements. Further, significantly, deficiency of iron is most prevalent in Calcareous type of soils in Tamil Nadu, India which causes chlorosis of the young leaves and at later stages they develop uniform pale green colour with darker green veins. As the deficiency intensifies, the vein loses their colour and all the parts of the leaf including petiole turns yellow and turns almost white. Excessive liming or fertilization with higher amounts of phosphorus can also induce iron deficiency. The characteristic symptom of magnesium deficiency is peculiarly noticed in subjacent leaves with interveinal chlorotic portions which beginning on edges of the foliar lobes and expanding inwards between the central and secondary veins (Zhang *et al.* 2015) which is also highly susceptible to magnesium deficiency in sandy soils, Ultisols and Oxisols.

The boron deficiency in cassava is characterized by reduced internodal length and also causes localized lesions on the stems and upper petiole and the lesions exudates brown substances and turn into cankers. Zinc deficiency in cassava causes inter-veinal chlorosis specifically develops small, white or light-yellow chlorotic spots between the veins. Silva *et al.* (2023) opined that cassava fertilization with optimal dose of 2.5 g plant⁻¹ exerted an improved tuber yield when compared to other treatments. Repeated cassava cultivation on the same field had declined micro nutritional status, which reflects the prevailing situations in Tamil Nadu. Similarly, regular application of NPK to cassava crop hampers the Cu and Zn status in soil (George, 2007). Nevertheless, of the cultivation practices, management of micronutrient deficiencies in cassava is the biggest problem faced under commercial cultivation wherein the farmer faces the drastic yield loss besides the complete crop loss. Considering its long duration nature and important industrial value and its suitability for cultivation in wide range of soils and climatic conditions, current investigation mainly aimed to compute the effect of combined application micronutrients and stake dipping for growth, yield of tuber and starch accumulation in tubers of cassava variety 'Sree Vijaya'. Stake (setts) dipping of cassava is a novel approach which was investigated as first of its kind in the present experiment for mitigating the micronutrient deficiency symptoms.

MATERIALS AND METHODS

Experimental Area: An investigation on micronutrient in cassava was done at TNAU, TCRS-Yethapur, Salem, Tamil Nadu, India. The geocoordinates of the investigational area was situated in Tamil Nadu state North Western region at an altitude of 282 MSL, 11° 35' N latitude and 78° 29' E longitudes. Nutritional status of the experimental field is furnished in table.1.

Table.1. Nutritional status of the experimental site

Parameters	Physico-chemical properties of soil	
	Initial	After harvest
pH	7.8	7.6
Organic carbon (%)	0.47	0.41
N kg ha ⁻¹ (available)	239	246
P kg ha ⁻¹ (available)	9.7	10.4
K kg ha ⁻¹ (available)	301.4	311.3
Ca (µg/g)	2.42	2.56
Mg (µg/g)	1.35	1.42
Fe (µg/g)	2.26	2.32
Zn (µg/g)	1.32	1.34
B (µg/g)	1.24	1.31

Details of experiment: The treatments were imposed for three seasons involving CTCRI, Thiruvananthapuram released variety ‘Sree Vijaya’ which is having the high yielding potential (25 to 28 t ha⁻¹) with starch content of 28%, having excellent cooking qualities. Tubers of this variety develops mild yellow colour after cooking. The experiment was laid out in Randomized Complete Block

Design (RCBD), with eight treatments repeated three time. The experimental area with uniformity in the soil fertility gradient was subdivided into eight equal sized plots of 4.5x4.5 m. Three such blocks were used to accommodate three replications and all the eight treatments were assigned randomly within a block. The schedule of treatments is furnished as follows.

Treatments	
T ₁	- Recommended Cultural Practices (RCP): FYM (25 t/ha) + NPK (90:90:240 Kg/ha) specific to the location ()
T ₂	- RCP + application of MgSO ₄ in soil at a rate of 20 kilograms per hectare
T ₃	- RCP + application of ZnSO ₄ in soil at a rate of 12.5 kilograms per hectare
T ₄	- RCP + application of Borax in soil at a rate of 10 kilograms per hectare
T ₅	- RCP + dipping the setts in 0.5% of FeSO ₄ solution
T ₆	- RCP + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare)
T ₇	- RCP + dipping the setts in 0.5% of FeSO ₄ solution + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare)
T ₈	- Absolute control (without any application of fertilizers, micronutrients and FYM)

The experiment was conducted for three seasons and between 2022 and 2024, the best treatment was validated through large scale demonstrations in farmers field. During the phase of execution of the experiment, the suggested dose of NPK was soil incorporated three months after planting while micronutrients *viz.*, borax, magnesium sulphate and zinc sulphate were applied between one and two months after planting. In addition to the above, dipping the setts (stakes) in ferrous sulphate solution for a period of fifteen minutes before planting and subsequently three to four times of foliar application with 0.5% Ferrous sulphate solution at an interval of weeks times and also on visualization of the deficiency symptoms. Setts or stakes were 10 to 15 cm lengthier stem cutting with 8 to 10 nodes which is used for commercial planting of cassava. This is the unique and pragmatic approach which was never tried in this cassava. Following the ridges and furrows technique, the setts were planted at 90 cm x 75 cm spacing. Standard cultivation practices were implemented uniformly for all experimental plots in accordance with the Horticultural Crop Production Guide (2020) recommendations. Furrow irrigation was used to maintain the plants, and irrigations were administered at weekly intervals from planting to three months after planting, and then at fifteen to twenty day intervals till harvest. Harvesting of tubers was done after 8 ½ months after planting of setts.

Growth parameters: During the maturity time, data on growth parameters *viz.*, height of the plant (cm), girth of stem (cm) were measured. Leaf area was calculated using Ramanujam and Indra (1978) methodology and expressed in cm².

Yield parameters: Yield contributing traits such as count on tubers per plant, tuber length (cm), tuber girth

(cm), yield of tuber per plant (kg) and yield of tuber per hectare (t) were recorded at the time of harvest.

Estimation of starch content: Starch accumulation in tubers was analyzed based on the methodologies suggested by Moorthy and Padmaja (2002) and calculated from the following formula.

$$\text{Starch (gram/100 gram WTF)} = \frac{10^a \times 100^b \times 0.9^c \times 100}{T \times 2^d \times 1000}$$

Where, ‘a’ is the titre obtained from ferricyanide reagent, ‘b’ is the total of starch hydrolysate volume, ‘c’ is 0.9 which is the Morris factor: for conversion of sugar to starch, T is titre value for starch hydrolysate and WTF is weight of tubers in fresh condition.

BC ratio: The cost involved for cultivation of crop was worked out by taking into account of various inputs for cultivation during the entire experiment period. Net income was derived by subtracting the cost of cultivation from the gross return. Benefit Cost ratio was computed as the ratio of gross return obtained from an area of one hectare to cultivation expenses/costs incurred for area of one hectare.

Weather parameters: The weather data recorded during the phase of experimentation is furnished in table.2 and the average *viz.*, minimum (22.46°C) and maximum temperature (32.49°C), relative humidity (65.86%) and rainfall (41.20 mm) was recorded.

Statistical Analysis: Data collected throughout the experimental period were statistically analyzed using AGRES and IRRISTAT 4.3 version. The results were interpreted at 0.05% probability level based on the methods of Panse and Sukhatme (1985) and Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The findings of the three seasons pooled data revealed that there was a remarkable divergence among the different micronutrient application and dipping of setts (stakes) in respect of growth and tuber yield parameters of cassava.

Effect of micronutrients on growth parameters of cassava: The soil application and dipping of setts (stake) in micronutrient solution brought out a substantial variation on height of the plant. The pooled mean data of three seasons disclosed that tallest cassava plants (182.98 cm) with girthiest stem (13.20 cm) was recorded in Recommended Cultural Practices (RCP): FYM (25 t/ha) + NPK (90:90:240 Kg/ha) specific to the location (T₁). The minimum plant height (150.94 cm) and girth stem (8.98 cm) was recorded in absolute control (T₈). Maximum number of green leaves (102.33) and minimum number of fallen leaves (71.33) was observed in RCP + dipping the setts in 0.5% of FeSO₄ solution (T₅) respectively. Application of micronutrients does not significantly influenced the area of leaf in cassava.

Plant growth parameters are much important for the production and synthesis of food materials which is then stored as carbohydrates in tuber of cassava plants. In addition to the above, micronutrients like Magnesium are the constituent of chlorophyll and chromosomes and acts as an activator of several enzymes *viz.*, hexokinase, phosphorylase, carboxylase and peptidases. Iron plays an important role in electron transport system in photosynthesis helps in energy generation besides the component of flavoproteins and active biological oxidation process. Thus, the proper application of Magnesium in the form of Magnesium Sulphate and dipping of setts (stake) in Ferrous Sulphate might have favoured the best vegetative growth by the way of greater count of green leaves, maximum area of leaf and minimum count of fallen leaves (Table 3). To supplement to the present investigation, Ifeanyi (2022) has also opined that in cassava, zinc plays significant role various enzyme systems for the production of energy, soluble nitrogen compound accumulation and regulation of growth. Similarly, iron is major component in many enzymes involved in the production of chlorophyll. Equally, magnesium plays a decisive performance on growth, concentration of chlorophyll, soluble protein and anti-oxidant enzyme activities of the plants. The present findings are similar with Srivastava (1996) and Mandal (2006), Suganya *et al.* (2020) and Omondi (2020) in cassava.

Effect of micronutrients on yield parameters of cassava: Tubers are economical part of cassava which decides the yield of the crops. During the phase of the experiment, tubers were harvested at 8 months stage, when there was a gradual leaf fall from base of stem to

top of the stem which the standard indicator or maturity index of cassava (Standard operating procedures for tuber crops, 2020). Differential micronutrient treatment and dipping of setts (stake) resulted in sizable variations in yield of tubers and its starch accumulation. It was found that the tuber numbers (9.53), tuber length (35.05 cm), tuber girth (19.37), yield of tuber (3.42 kg plant⁻¹ and 35.93 t ha⁻¹) and tuber starch content (24.60%) was excelled in RCP + dipping the setts in 0.5% of FeSO₄ solution + combined application of micronutrients in soil: MgSO₄ (20 kilograms per hectare) + ZnSO₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T₇) (Table 4 and 5, Figure 1, 2). The yield contributing parameters such as count of tubers, lengthiest and girthiest tuber, per plant yield of tuber and starch content are the important factors which decides the profit of growers. The tuber length and girth decide the marketable size of the tubers. The maximum accumulation of carbohydrates in tubers decides the overall tonnage of the crop.

In addition to the above, the highest tuber dry weight (0.729 kg plant⁻¹) was recorded in RCP + dipping the setts in 0.5% of FeSO₄ solution + combined application of micronutrients in soil: MgSO₄ (20 kilograms per hectare) + ZnSO₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T₇). The results obtained from the present trial are in corroboration with the results of Howeler *et al.* (1982) and Suganya *et al.* (2020) in cassava.

Micronutrients are required in smaller quantities or trace amounts which cater the normal growth and development of cassava. Magnesium was found in tetrapyrrolic chlorophyll which plays marked role as an activator of hexokinase, phosphorylase, dehydrogenase and peptidases. Iron was absorbed in ferrous form and plays vital role in transport system of electron in photosynthesis process and respiration besides generation of energy. Soil pH controls the iron availability to crop plants. Further iron had greater role as a component of flavoprotein in biological oxidation processes and iron porphyrin proteins which includes peroxidases and catalases. Pentose phosphate shunt in carbohydrate metabolism was regulated by boron besides facilitating the sugar translocation in plants.

Further, Silva *et al.* (2023) affirmed that cassava variety 'IAC 576-70' responded well for the application of ZnSO₄ with incremental growth of main stem. Zinc interferes with various plant biochemical pathways and also with the growth regulators like auxins. The dry matter accumulation of tubers of cassava is highly favoured by the intervention of zinc which was also evident from the present investigation.

The availability of zinc was decreased with substantial increase in pH of soil. Tryptophan synthesis and activators of various metabolisms were regulated by the zinc which upon deficient leads to detrimental effects to

Table.2. Weather parameters recorded during the period of experimentation

Months	Season-1 (Experimental trial)				Season-2 (Experimental trial)				Season-3 (Confirmatory trial)				Season-4 (Large scale demonstration)				Season-5 (Large scale demonstration)			
	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)
	Max	Min		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
January	30.9	13.5	0	23.3	19.1	65.1	65.1	29.3	16.8	45.7	45.7	30.3	19.0	12.0	78.9	78.9	29.60	25.10	58.10	58.10
February	32.9	16.7	0	36.0	19.1	65.1	65.1	33.7	19.3	69.9	69.9	32.1	18.2	0.0	75.3	75.3	32.30	16.90	46.90	46.90
March	30.9	13.5	0	39.2	31.6	15.8	15.8	36.4	21.2	71.5	71.5	31.3	18.7	33.0	60.4	60.4	32.10	19.85	61.30	61.30
April	38.9	24.7	0	37.3	24.3	63.3	63.3	25.09	36.55	57.44	57.44	33.3	23.6	26.5	58.5	58.5	36.60	23.50	58.90	58.90
May	37.1	25.6	4.9	36.0	25.5	59.8	59.8	37.03	24.50	61.95	61.95	30.5	22.2	94.0	64.0	64.0	35.40	25.60	73.10	73.10
June	36.1	26.2	1.1	36.4	25.9	56.3	56.3	36.19	25.05	61.53	61.53	36.1	27.2	157.0	62.0	62.0	34.20	24.21	66.29	66.29
July	35.9	25.7	0.6	41.8	24.7	62.5	62.5	35.67	24.75	64.57	64.57	30.7	23.0	70.0	68.9	68.9	34.20	24.73	69.91	69.91
August	34.6	24.6	3.7	37.6	25.3	67.3	67.3	35.88	24.16	57.83	57.83	27.3	19.5	92.5	64.1	64.1	36.10	24.50	66.90	66.90
September	34.7	24.5	2.9	35.0	24.3	69.3	69.3	36.30	24.95	71.40	71.40	32.6	23.2	55.5	80.4	80.4	33.70	24.10	52.00	52.00
October	20.8	23.4	6.2	29.2	23.9	64.1	64.1	34.63	23.56	80.38	80.38	31.4	22.3	255.5	82.5	82.5	33.70	23.20	81.30	81.30
November	29.3	20.3	1.4	28.8	21.9	85.2	85.2	32.24	20.59	73.75	73.75	29.3	20.5	114.9	83.8	83.8	31.0	22.80	83.40	83.40
December	29.0	20.1	0.3	2.8	21.3	82.6	82.6	30.81	7.74	67.52	67.52	27.3	19.5	20.5	74.6	74.6	30.80	21.70	70.40	70.40

Source of information: Meteorological observatory, TCRS, Yelhapur

Table.3. Effect of micronutrients on growth parameters of cassava variety 'Sree Vijaya'

Treatments	Plant height (cm)			Stem girth (cm)			Leaf area (cm ²)			Number of green leaves			Number of fallen leaves							
	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3					
Recommended Cultural Practices (RCP) specific to the location (T ₁)	170.40	184.63	193.90	182.98 ^a	11.90	13.20	14.50	13.20	923.3	811.0	872.3	868.87	107	71	126	101.33	84	115	89	96.00 ^a
RCP + application of MgSO ₄ in soil at a rate of 20 kilograms per hectare (T ₂)	178.90	169.66	178.10	175.55 ^a	12.80	10.94	11.30	11.68	825.1	793.9	864.7	827.90	115	75	117	102.33	71	114	81	88.67 ^b
RCP + application of ZnSO ₄ in soil at a rate of 12.5 kilograms per hectare (T ₃)	138.10	141.26	168.90	149.42 ^d	11.40	10.26	9.30	10.32	695.9	729.6	809.5	745.00	98	62	94	84.67	69	81	78	76.00 ^d
RCP + application of Borax in soil at a rate of 10 kilograms per hectare (T ₄)	159.80	163.16	171.30	164.75 ^b	9.80	9.10	8.70	9.20	702.1	736.4	829.7	756.07	105	66	115	95.33	76	104	77	85.67 ^b
RCP + dipping the setts in 0.5% of FeSO ₄ solution (T ₅)	155.90	149.40	156.90	154.07 ^{cd}	9.00	8.90	9.90	9.27	735.6	757.0	854.0	782.20	99	73	97	89.67	53	91	70	71.33 ^e
RCP + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) +	161.30	156.00	176.80	164.70 ^b	12.00	10.05	10.00	10.68	811.6	840.7	804.2	818.83	103	64	102	89.67	70	86	77	77.67 ^c

ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₆)	152.30	159.83	167.80	159.98 ^{bc}	13.00	11.82	12.90	12.57	890.2	876.5	908.4	891.70	110	73	91	91.33	66	110	93	89.67 ^b
RCP + dipping the setts in 0.5% of FeSO ₄ solution + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₇)	144.60	150.13	158.10	150.94 ^{cd}	8.00	9.35	9.60	8.98	731.9	705.2	760.8	732.63	85	59	132	92.00	93	98	64	85.00 ^b
Absolute control (T ₈)	14.23	25.09	NS	10.19	6.56	3.06	5.34	NS	41.7	NS	NS	NS	9.13	8.64	9.84	NS	7.28	8.21	6.89	7.11
SEd	7.11	12.45		5.06	3.28	1.53	2.67		20.8			4.56		4.32	4.92		3.63	4.11	3.44	3.54

Table.4. Effect of micronutrients on number of tubers plant⁻¹, length of tuber (cm) and girth of tuber (cm) of cassava variety ‘Sree Vijaya’

Treatments	Number of tubers plant ⁻¹			Length of tuber (cm)			Girth of tuber (cm)			
	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Pooled mean
Recommended Cultural Practices (RCP) specific to the location (T ₁)	7.0	7.3	6.7	31.20	35.30	25.62	12.30	15.50	12.00	13.27 ^e
RCP + application of MgSO ₄ in soil at a rate of 20 kilograms per hectare (T ₂)	5.9	6.7	6.0	27.93	31.63	23.52	19.30	17.00	11.00	15.77 ^{cd}
RCP + application of ZnSO ₄ in soil at a rate of 12.5 kilograms per hectare (T ₃)	9.6	8.7	6.3	25.60	33.16	30.54	17.60	20.83	14.35	17.59 ^{ab}
RCP + application of Borax in soil at a rate of 10 kilograms per hectare (T ₄)	7.3	6.1	5.5	32.60	29.10	21.41	17.00	15.10	10.00	14.03 ^{de}
RCP + dipping the setts in 0.5% of FeSO ₄ solution (T ₅)	7.0	5.4	5.8	33.30	30.43	18.95	15.60	17.20	8.95	13.92 ^e
RCP + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₆)	10.3	9.4	6.8	29.10	35.70	32.81	16.60	19.53	15.50	17.21 ^{bc}
RCP + dipping the setts in 0.5% of FeSO ₄ solution + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₇)	11.3	9.9	7.4	31.60	38.80	34.75	19.60	21.20	17.30	19.37 ^a
Absolute control (T ₈)	5.6	6.3	5.5	25.10	29.16	22.11	15.30	18.20	10.35	14.62 ^{de}
CD (0.05)	2.1	1.97	0.57	2.24	4.13	2.41	1.93	NS	1.67	1.76
SEd	1.0	0.98	0.28	1.12	2.07	1.20	0.96	NS	0.84	0.87

Table.5. Effect of micronutrients on tuber yield plant⁻¹ (kg), tuber yield (t ha⁻¹) and starch content (%) of cassava variety 'Sree Vijaya'

Treatments	Tuber yield plant ⁻¹ (Kg)			Tuber yield (t ha ⁻¹)			Starch content (%)						
	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Pooled mean			
Recommended Cultural Practices (RCP) specific to the location (T ₁)	2.00	2.25	2.99	2.41 ^{bcd}	28.45	29.06	24.92	27.48 ^c	23.50	22.10	22.10	22.10	22.57 ^c
RCP + application of MgSO ₄ in soil at a rate of 20 kilograms per hectare (T ₂)	1.96	2.59	2.75	2.43 ^{bcd}	29.35	31.40	28.75	29.83 ^{bc}	24.00	22.10	22.10	23.80	23.30 ^{bc}
RCP + application of ZnSO ₄ in soil at a rate of 12.5 kilograms per hectare (T ₃)	2.60	2.47	3.49	2.85 ^{bc}	30.80	30.50	27.42	29.57 ^{bc}	23.50	21.10	21.10	24.90	23.17 ^{bc}
RCP + application of Borax in soil at a rate of 10 kilograms per hectare (T ₄)	2.30	2.14	2.50	2.31 ^{cd}	28.20	27.89	23.75	26.61 ^c	23.90	20.10	20.10	23.80	22.60 ^c
RCP + dipping the setts in 0.5% of FeSO ₄ solution (T ₅)	2.21	2.32	2.24	2.26 ^d	31.10	29.10	25.66	28.62 ^c	24.00	23.20	23.20	22.00	23.07 ^{bc}
RCP + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₆)	2.69	2.84	3.29	2.94 ^{ab}	33.60	32.68	30.93	32.40 ^b	24.60	23.10	23.10	24.10	23.93 ^{ab}
RCP + dipping the setts in 0.5% of FeSO ₄ solution + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₇)	3.11	3.06	4.08	3.42 ^a	36.71	36.22	34.85	35.93 ^a	25.00	23.30	23.30	25.50	24.60 ^a
Absolute control (T ₈)	1.69	1.28	2.58	1.85 ^d	25.60	18.58	20.98	21.72 ^d	23.50	20.40	20.40	22.90	22.27 ^c
	CD (0.05)	0.92	0.33	0.45	5.10	3.87	3.61	3.51	3.09	3.77	3.77	1.31	1.06
	SEd	0.45	0.16	0.22	2.55	1.93	1.80	1.74	1.53	1.88	1.88	0.65	0.51

Table.6. Effect of micronutrients on HCN (ppm), tuber dry weight (kg plant⁻¹) and cost economics of cassava variety 'Sree Vijaya'

Treatments	HCN (ppm)			Tuber dry weight (Kg plant ⁻¹)			Cost economics			
	Season - 1	Season - 2	Season - 3	Season - 1	Season - 2	Season - 3	Cost of cultivation (Rs/ha)	Gross income (Rs./ha)	Net income / Net profit (Rs./ha)	BC ratio
Recommended Cultural Practices (RCP) specific to the location (T ₁)	70.10	72.00	72.57	0.564	0.534	0.556	755000	164880	89380	2.18
RCP + application of MgSO ₄ in soil at a rate of 20 kilograms per hectare (T ₂)	63.90	69.00	68.47	0.511	0.586	0.615	762000	193895	117695	2.54
RCP + application of ZnSO ₄ in soil at a rate of 12.5 kilograms per hectare (T ₃)	61.20	65.00	65.13	0.698	0.631	0.675	761250	192205	116080	2.52
RCP + application of Borax in soil at a rate of 10 kilograms per hectare (T ₄)	66.90	61.00	64.00	0.471	0.494	0.509	772000	159660	82460	2.07
RCP + dipping the setts in 0.5% of FeSO ₄ solution (T ₅)	58.50	55.00	57.43	0.649	0.621	0.537	755870	186030	110420	2.46
RCP + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₆)	65.30	69.00	68.57	0.691	0.649	0.668	785250	210600	132075	2.68

RCP + dipping the setts in 0.5% of FeSO ₄ solution + combined application of micronutrients in soil: MgSO ₄ (20 kilograms per hectare) + ZnSO ₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T ₇)	65.80	62.00	60.10	62.63	0.703	0.681	0.804	0.729 ^a	786120	287440	208827	3.66
Absolute control (T ₈)	59.00	54.50	55.9	56.47	0.397	0.436	0.440	0.424 ^f	555000	108600	53100	1.96
CD (0.05)	NS	11.03	7.42	NS	0.21	0.13	0.12	0.05				
SEd		5.49	3.71		0.10	0.07	0.05	0.02				



Fig.1. Occurrence of micronutrient deficiency in cassava



T₇ - POP + MgSO₄ + ZnSO₄ + Borax + FeSO₄



T₈ - Absolute control

Fig.2. Performance of cassava variety 'Sree Vijaya' to the application of micronutrients and setts dipping

cassava. Cassava being a tuberous crop, the count of tubers, length and girth of tubers followed by yield of tubers and starch accumulation of the tubers is most important for achieving the economic yield. In this way, the results derived from this research experiment is in line with the findings of Indra *et al.* (1997), White *et al.* (2009), Lebot (2009), Susan John (2011), Tsonev and Lidon (2017), Janket *et al.* (2018), Ifeanyi (2022) and Silva *et al.* (2023) in cassava. However, the application of different combination of micronutrients did not influence the HCN content of tubers (Table 6).

Effect of micronutrients on economics of cassava:

The analysis of cost of cultivation is imperative in any production of crops like cassava which aims at higher profit realized out of the minimal use of agro-inputs. Being an industrial crop, from the farmer's perspectives, minimal use of fertilizers and other plant protection chemicals subsequently reduce the labour required for application in the field conditions which in turn make the grower to realize more profit. The application of micronutrients expressed the significant profit realizations in cassava. The maximum net profit/income (INR 208827) with BC ratio of 3.66 was realized in the treatment RCP + dipping the setts in 0.5% of FeSO₄ solution + combined application of micronutrients in soil: MgSO₄ (20 kilograms per hectare) + ZnSO₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T₇). The lowest income (INR 53100) with BC ratio of 1.96 was obtained in absolute control or the farmers practice without any application of micronutrients (Table 6). The outcomes of the current investigation are consistent with the conclusions of Suganya *et al.* (2020), Janket *et al.* (2021), Ifeanyi (2022) and Silva *et al.* (2023) in cassava. The present finding is a great boon to the cassava growers where in the plants are healthy and

free from micronutrient deficiencies with incremental benefit of high economic returns from the cassava crop.

Conclusion: The combined application of micronutrient on cassava with novel approach on dipping of setts (stake) in micronutrient solution had profound role on the growth and tuber yield especially maximum count of tubers (9.53), lengthiest tuber (35.05 cm), girthiest tuber (19.37), yield of tuber (3.42 kg plant⁻¹) and starch accumulation in tubers (24.60%) was exemplary in RCP + dipping the setts in 0.5% of FeSO₄ solution + combined application of micronutrients in soil: MgSO₄ (20 kilograms per hectare) + ZnSO₄ (12.5 kilograms per hectare) + Borax (10 kilograms per hectare) (T₇). The same treatment put forth highest BC ratio when compared to other micronutrient treatments including the farmers practice (control).

Conflicts of Interest: The authors declare that there is no conflict of interests regarding the publication of this manuscript.

Ethical Statement: Ethical approval is not required for this study.

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Authors Contribution: MV Conceptualization, Planning of experiment and manuscript writing, SM, LP & GB Supervision and Project Management, TK, MA & PRK statistical analysis, VR Editing of tables, TSP & EP manuscript editing, SS lab analysis

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