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Consortium Biofertilizers to Economise Nutrient use and Sustain Productivity in Cassava (*Manihot esculenta* Crantz)

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***Abstract*:** Climate change events and COVID 19 pandemic have brought to focus the significance of cassava as a supplementary food crop worldwide. However, the high yield potential of the crop necessitates timely and adequate enrichment of soil with nutrient inputs. Consortium biofertilizers offer a viable option for reducing intensive fertilizer use to sustain soil heath and productivity in cassava. The efficacy of liquid consortium biofertilizer, plant growth promoting rhizobacteria (PGPR) Mix - I in economizing nutrient use in cassava were evaluated in a 4 x 3 factorial randomized block design replicated thrice. Combinations of four levels of biofertilizers and three levels of nutrients comprised the treatments. The biometric and yield observations were recorded and soil properties analyses, pre and post harvest of the crop. The liquid biofertilizer consortium at 5 % concentration + 75 % recommended dose, 37.5: 37.5: 75 kg NPK ha^{-1} as chemical fertilizers recorded the ssignificantly superior tuber yield in cassava. Considering the economics, application of PGPR liquid formulation (5 %) thrice (basal, 2 and 4 MAP), along with 37.5: 37.5: 75 kg NPK ha^{-1} or at 2 % concentration with 50:50:100 kg NPK ha^{-1} realized higher benefit-cost ratios and can be recommended in cassava.

***Keywords*:** Biofertilizer, Cassava, Nutrient, PGPR, Tuber yield

Cassava (*Manihot esculenta* Crantz), belonging to the family Euphorbiaceae, is a benchmark of food security being an affordable crop for the poor. The crop has proved to be life sustaining in times of natural calamities and famine. Compared to other food crops, cassava is bestowed with the ability to grow on marginal lands and are climate resilient. The yield potential ranges from 25 to 43.4 Mg ha^{-1} (John et al 2007) which is suggestive of its high potent bioconversion efficiency. This implies that the crop is a heavy feeder of nutrients. The nutrient removal by cassava is estimated to be 180, 22 and 160 kg N, P and K ha^{-1} respectively for 30 t ha^{-1} tuber yield (John et al 2019), necessitating a regular supply of nutrient inputs and the recommendations converges to an NPK dose of 100 kg each of N, P and K (KAU 2016), modified based on site specific soil test data. Scientific studies illustrate the use of chemical fertilizers as the source of nutrients and the practice was enormously encouraged among the farming community. Nevertheless, over the years, soil, the fountain of life has borne the maximum impact of the indiscriminate chemical use as a result of which the biology that sustained quality has been hampered (Alori and Babalola 2018). The escalating cost of chemical fertilizers and the increasing awareness on the ill effects of imperceptive chemical use have led to the added interests on integrated nutrient management practices in which organic and bio nutrient inputs can partly substitute chemical fertilizers in satisfying the crop nutrient requirements. Bio nutrient inputs focus on the microbial formulations intended to enhance the availability of nutrients to crop plants. Howbeit, being single microbe based, the adoption and use are constrained by the specificity for nutrients and need for multiple and separate inoculation for each nutrient during crop growth. This paved way for the development of consortium biofertilizers that have the advantage of a heterogeneous population of plant growth promoting rhizobacteria in a single inoculum, assuring mineralisation and solubilisation of different nutrients with a use of single formulation amending the earlier disadvantage. Gopal (2018) have illustrated the superiority of consortium formulations over the single inoculum biofertilizer. In light of the above, talc based and liquid formulations of Plant Growth Promoting Rhizobacteria (PGPR) Mix-I were developed by the Department of Agricultural Microbiology, College of Agriculture, Vellayani under Kerala Agricultural University, India which were tested for its efficacy in different crops (Jayapal, 2012). The consortium includes nitrogen (N) fixers (*Azospirillum lipoferum, Azotobacter chroococcum*), phosphorus (P) solubiliser (*Bacillus megaterium*) and potassium (K) solubiliser (*Bacillus sporothermodurans*).

As biofertilizers add to the soil flora of beneficial microorganisms and enhance nutrient solubilisation, a field experiment was undertaken in cassava (*Manihot esculenta* Crantz), the most popular tuber crop in Kerala in the southern laterites (Agroecological Unit 8), to assess the efficacy of PGPR formulations in sustaining productivity and economising nutrient use.

MATERIA AND METHODS

Site and experimental conditions: The field experiment was conducted at Kerala Agricultural University during June to December 2019. The site falling under the agroclimatic zone and agroecological unit 8 (Southern laterites) is located at 8°30'N latitude, 76°54'E longitude and at an altitude of 29 m above mean sea level and experienced a warm humid tropical climate with a maximum and minimum temperatures ranging from 29.5 to 34.1°C and 26.1 to 23.6°C respectively, relative humidity from 87.1 to 94.6 % during the cropping period. The precipitation received during the cropping period was 267.3 mm, mainly during the months of June- July and October- November 2019. Soil was sandy clay loam in texture belonging to the order ultisol. Chemical properties assessed revealed the soil to be strongly acidic (pH, 5.23), high in organic carbon (1.25 %), medium in N (294.37 kg ha^{-1}) and K (138.32 kg ha^{-1}) and high in P (42.63 kg ha^{-1}) before cropping.

The experiment was laid out in factorial randomized block design with two factors, biofertilizers [b_1: PGPR Mix -I liquid (@ 2 % ; b_2: PGPR Mix -I liquid (@ 5 %; b_3: PGPR Mix -I powder @ 10 g of 2 % mixture per plant ; b_4: without biofertilizer] and nutrient levels [n_1: 50 %; n_2: 75 % ; n_3: 100 % of recommended dose of nutrients (RDN), 50:50:100 kg NPK ha^{-1}]. After land preparation, dried and powdered farmyard manure was incorporated with final ploughing and mounds taken at a spacing of 90 cm x 90 cm in the individual plots. Cassava setts (20 cm long cuttings of stem, 4-5 nodded) of short duration variety Vellayani Hraswa, (5-6 months) were planted with two nodes of each set below the soil and remaining nodes above. The basal dose of nutrients were given with straight fertilizers, urea, rajphos and potash as per the treatments. The biofertilizers were applied thrice, at planting (one week after fertilizer application), 2 and 4 months after planting (MAP). The 2 and 5 % concentrations of PGPR Mix -I liquid were prepared by mixing 20 mL and 50 mL of liquid consortium in 1000 mL water respectively. From the prepared solution 200mL was applied in the root zone, on each mound according to the treatments. The mixture of the powder formulation was prepared by mixing 20 g talc based PGPR Mix-I with one kg of powdered cow dung and 10 g of the mixture was applied on each mound. Full dose of P was applied basally, N and K were given in three equal splits (basal, 1 and 2 MAP) using the chemical fertilizers, urea, rajphos and muriate of potash.

Biometric and yield observations: Three plants were randomly selected from the net plot area and tagged as observational plants for recording biometric observations. Cultural operations were done as per the recommended package for cassava. The crop was ready for harvest, six months after planting (MAP). The mounds were irrigated on the previous day of harvest and on the day of harvest, soil at the plant base was loosened by light digging. The plant top was cut and the remaining stump was pulled out carefully with tubers intact. Tubers were cut from the stem and weighed to record the fresh weights. The length and girth of ten randomly selected tubers in each treatment were measured and recorded. The tubers were also weighed individually to record the mean weights. The per hectare yields were computed from the yields recorded in treatment wise the net plot area in each treatment.

Plant analysis: Samples of stem, leaves and tuber collected for chemical analysis were dried separately in an air oven at 70 ± 5°C and ground to pass through 0.5 mm mesh. The N content of the plant parts was determined separately by modified micro Kjeldahl method (Jackson, 1973). The P content was estimated calorimetrically (Jackson 1973) and K content by flame photometry method (Piper 1967). The total uptake of N, P, and K at harvest were calculated by multiplying the respective nutrient content in the stem, leaf and tuber with their corresponding dry weights and expressed in kg ha^{-1}.

Economics: The economics of cultivation of the crop was worked out in terms of the returns per rupee invested (benefit cost ratio) based on the cost of cultivation and gross income realized.

Statistical analysis: The data on the biometric and yield parameters were analysed using OP Stat software.

RESULTS AND DISCUSSION

Biometric Observations

Growth attributes: The growth attributes in cassava, plant height, number of functional leaves per plant and leaf area index (LAI) varied significantly with PGPR application and varying nutrient doses (Table 1 and 2) and indicated their favourable influence on the vegetative growth. All the parameters were found to be maximum at the harvest stage, in accordance with the growth phenology of cassava.

The plant height was maximum with PGPR (L) @ 5 % (b_2) application and among the nutrient levels, n_2 (75% RDN) at 2 and 4 MAP (66.1 cm and 99.5 cm respectively) and n_1 (50 % RDN) at harvest, were significantly superior. The interaction effects were significant and PGPR (L) 5 % in combination with 75 % RDN at 2 and 4 MAP (82.3 and 114.3 cm respectively) and with 50 % RDN at harvest, recorded the tallest plants, the latter on par with 75% RDN. The number of functional leaves and leaf area index (LAI) varied significantly with the individual effects of biofertilizers and nutrient levels. Maximum values were observed with liquid PGPR @ 5 % (b_2) and 75 % RDN (n_2) at all stages of growth. The effects were reflected in the interaction and b_2n_2 recorded the highest number of functional leaves and LAI at all stages of growth and the lowest were in treatment b_0n_1 (50 % RDN without biofertilizer). Biofertilizer consortium as a complementary nutrient input in crop production has been studied by several workers (Dhanya 2011, Jayapal 2012, Radhakrishnan et al 2013, Suja et al 2014, Gopi 2018). Singh (2013) confers better plant growth promotion ability to PGPR as the consortium, apart from the nutrient supplying potential are able to synthesise phyto hormones, decompose organic matter, enlarge the soil flora and improve the soil structure for root development and better absorption of water and nutrients. Gautam et al (2017) observed that application of liquid based biofertilizer as well as carrier based biofertilizers reinforced the rhizosphere microbiome due to availability of carbon and energy sources in the rhizosphere. When chemical fertilizers are used solely, the chances of nutrient losses are high, and microbial activity, the key regulator of improved soil health is meagre, which would have led to its comparatively poorer performance. Ansari et al (2015) reported 21 to 50 % increase in the chick pea dry seed yields with liquid biofertilizer application in pot culture study and nearly 144 % increase in the field experiment over the uninoculated control. Kaur et al (2018) discerned the enhancement in wheat yields with liquid biofertilizers to the direct and indirect mechanisms such as biological nitrogen fixation, phosphate solubilization, phytohormone production and 1-aminocyclopropane-1-carboxylic acid (ACC 1)

Table 1. Effect of biofertilizer and levels of nutrients on growth attributes in cassava

Treatments	Plant height (cm)			Number of functional leaves			LAI		
	2 MAP	4 MAP	Harvest	2 MAP	4 MAP	Harvest	2 MAP	4 MAP	Harvest
Biofertilizer (B)									
b_1 - PGPR (L) 2 %	61.69	92.96	170.48	26.40	45.41	73.59	1.38	2.34	4.17
b_2 - PGPR (L) 5 %	68.11	107.58	188.14	28.67	47.78	79.67	1.64	2.64	4.35
b_3 - PGPR (P)	64.88	103.88	144.44	28.29	42.56	73.18	1.41	2.21	3.97
b_0 - without biofertilizer	40.00	79.47	123.81	26.40	42.44	69.96	1.34	2.18	3.74
CD (p=0.05)	1.385	1.076	1.862	1.172	0.891	0.923	0.055	0.059	0.09
Levels of nutrients (N)									
n_1 - 50 % RDN	51.19	96.19	162.19	25.80	42.41	71.52	1.33	2.13	3.64
n_2 - 75 % RDN	66.11	99.46	153.52	29.63	47.11	75.86	1.56	2.58	4.35
n_3 - 100 % RDN	58.83	92.27	154.52	26.88	43.86	74.91	1.44	2.33	4.19
CD (p=0.05)	1.190	0.932	1.614	1.014	0.775	0.803	0.031	0.052	0.080

L: Liquid P- Powder RDN- 50: 50: 100 kg NPK ha^{-1}

Table 2. Interaction effects of biofertilizer and levels of nutrients on growth attributes

Treatments	Plant height (cm)			Number of functional leaves			LAI		
	2 MAP	4 MAP	Harvest	2 MAP	4 MAP	Harvest	2 MAP	4 MAP	Harvest
b_1n_1	47.33	88.66	154.56	24.67	44.55	73.11	1.26	2.12	3.75
b_1n_2	72.23	99.77	177.33	28.56	46.55	73.00	1.47	2.55	4.45
b_1n_3	66.33	90.44	179.56	26.00	44.11	74.67	1.41	2.34	4.32
b_2n_1	69.33	108.44	193.00	26.67	45.22	76.78	1.60	2.32	3.83
b_2n_2	82.33	114.32	195.00	32.22	54.11	85.22	1.83	3.15	4.63
b_2n_3	52.66	99.91	176.44	27.11	44.00	77.00	1.50	2.46	4.17
b_3n_1	52.44	109.44	187.11	28.44	43.33	71.56	1.36	2.17	3.62
b_3n_2	67.55	108.55	124.33	30.44	43.00	74.44	1.48	2.40	4.08
b_3n_3	74.67	93.66	121.88	26.00	41.33	73.55	1.41	2.08	4.22
b_0n_1	35.66	78.21	114.11	23.44	36.55	64.67	1.10	1.92	3.38
b_0n_2	42.33	75.21	117.11	27.33	44.78	70.78	1.46	2.21	3.80
b_0n_3	41.67	84.99	140.22	28.44	46.00	74.44	1.47	2.44	4.05
CD (p=0.05)	2.394	1.862	3.223	2.028	1.544	1.606	0.09	0.114	0.160

deaminase activity and siderophore production. Vendan and Thangaraju (2006) documented the advantages of liquid formulations of biofertilizers over powder formulation to include higher microbial counts, near zero contamination, greater protection against environmental stresses and increased field efficacy. According to Hoe and Rahim (2010), liquid biofertilizers have more viable cells than carrier based biofertilizers. Apart from the desired microorganisms and their nutrient solubilising properties, liquid biofertilizers also contain special cell protectants or substances that encourage the formation of resting spores or cysts for longer shelf life (Chandra et al 2005, Hegde 2002). Glycerol amended PGPR liquid formulation used in the present study, had the advantage of enhanced tolerance of cells to desiccation, osmotic pressure and temperature stress (Gopi et al 2020) due to induced synthesis of metabolites that offer protection against the stress (Kumaresan and Reetha, 2011).

The better performance of liquid biofertilizers over carrier based formulations as observed are in accordance with the reports of Maheswari and Kalayarasi (2015), Gopal (2018) and Lakshmi et al (2019). Among the two concentrations of the liquid formulations, the 5 % concentration was found to be superior. Although Gopi et al (2018) recommended 2 % concentration of PGPR (L) + 50 % RDN to be effective in a 45 day old crop of *Amaranthus tricolor,* in the present study it is reasoned that cassava variety Vellayani Hraswa, being a crop of longer duration (180 days) required a higher concentration (cell count) to realise the benefits of the formulation.

The NPK recommendation, 50: 50: 100 kg ha^{-1} found ideal for short duration variety Vellayani Hraswa (Sekhar, 2004) was the nutrient dose (RDN) adopted for the experiment. Nevertheless, the results revealed that among the different levels, 75 % of RDN (37.5: 37.5: 75 kg NPK ha^{-1}) was superior to produce a good vegetative frame of the crop and tuber yield (42.11 Mg ha^{-1}) indicating the sufficiency of 37.5 kg each of N and P and 75 kg K ha^{-1}, a saving of 25 percent of fertilizers and costs. Tuber yield was the lowest in n_1 where 50 % of RDN (25: 25: 50 kg NPK ha^{-1}) was applied. Cassava is known to be a heavy feeder and it is reckoned that this lower dose was inadequate. The positive response of the former on growth parameters (number of functional leaves and LAI) and the yield attributes (number of tubers per plant, mean tuber weight, length of tuber and girth of tuber) that influenced the yield of the crop have contributed to the significantly highest yield over the latter. The combination of 5 % PGPR Mix-I liquid and 75 % RDN recorded the highest values for the yield attributes (Table 3). The increased uptake of nutrients from soil with the integrated application of nutrients and biofertilizers would have produced enough carbohydrates in the leaves for translocation to the sink for better tuber number and bulking, thereby favouring better tuber yield. The higher LAI and tuber parameters realised in b_2n_2 indicate a better source sink balance and hence better productivity in this treatment.

Yield attributes and yield: The superiority of the liquid formulation @ 5% in enhancing tuber production is evident in terms of the number of tubers per plant (8.7) and mean tuber weight (0.67 kg) and tuber yields (5.0 kg per plant) (Table 3). Among the nutrient levels, 75 % RDN showed maximum weight (0.59 kg), number of tubers (8.86) and tuber yield per plant (4.77 kg). The interaction, b_2n_2 was superior among treatment combinations producing the highest number of tubers per plant (10.00) and mean tuber weight (0.78 kg). Tuber yield per plant (5.12 kg) was also the highest in b_2n_2. The per hectare yields followed the same trend with the maximum yield (44.49 Mg ha^{-1}) in the combination of liquid formulation of PGPR @ 5 % + 75 % RDN followed by b_1n_3 [PGPR (L) 2 % + 100 % RDN] (Table 3). The yields were 44.49 and 42.32 Mg ha^{-1} respectively and 11 and 17 % higher than the application of chemical fertilizers at the recommended dose without biofertilizers. Harvest index in the b_2n_2 combination was the highest. Exploring the individual effects, application of biofertilizer. PGPR liquid formulation at 5 % and fertilizers at 75 % RDN showed significantly higher HI (0.79 and 0.72 respectively) but in the latter, n_2 (75 % RDN) was on par with n_3 (100 % RDN). Suja et al (2005) reported that integrated use of bioinoculants (*Azospirillum* and *Phosphobacter*), organic manures,100 % K, 50 % of N and P produced tuber yields on par with the recommended dose of fertilizers (50: 50: 100 kg NPK ha^{-1}) for cassava implying the possibility of reducing N and P fertilizers to 50 % in cassava.

Nutrient uptake: The N, P and K uptake were higher with the inclusion of biofertilizers, (Fig. 1), the maximum in b_2 and the nutrient dose of 75% RDF (n_2). Suja et al (2010) also observed significant effect of fertility levels on the NPK uptake in cassava. Among interactions b_2n_2 was also superior for all nutrients. The highest uptakes to be 203.07, 62.81 and 188.02 kg ha^{-1} for N, P and K respectively (Fig. 2).

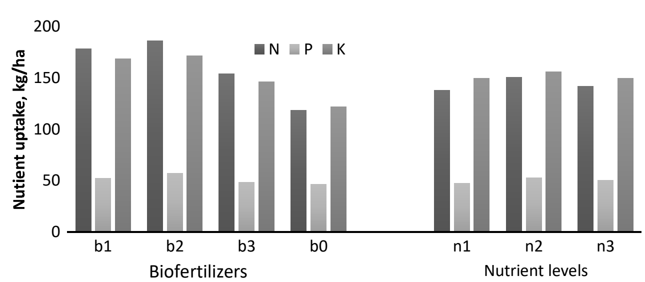

Fig. 1. Nutrient uptake in cassava as influenced by biofertilizers and different nutrient levels

Nutrient uptake by crop is a function of nutrient content in dry matter and the dry matter production and nutrient content is related to the photosynthetic activity of leaves. The uptake of N, P and K were the highest in the treatment with 5 % PGPR (L) followed by 2 % PGPR (L) followed the order N > P > K. The better plant growth observed in biofertilizer included treatments, would have resulted in improved nutrient absorption and higher biomass production that ensued the higher nutrient uptake and better yields. It is also interpreted that the addition of biofertilizers augmented the microflora and rhizospheric processes that created a conducive environment for better uptake.

Economics: The highest ratio (3.20) was in the combination of 2 % PGPR (L) consortium + 100 % RDN followed by the 5 % PGPR (L) with 75 % RDN (3.07). The benefit cost ratio with the use of 2 % concentration (3.2) was higher than that with the 5 % formulation (3.07) on account of the higher input cost, involved in the preparation of 5 % PGPR (L) and cost of fertilizers, The lowest B:C ratio recorded in the treatment combination of PGPR Mix-I powder and full dose RDN is attributed to the high cost of powder formulation and cost of FYM in applying the mixture. Thus taking into account the economics, application of 2 % formulation thrice (basal, 2 and 4 MAP) along with 50: 50: 100 kg NPK ha^{-1} or 5 % liquid formulation + 37.5: 37.5: 75 kg NPK ha^{-1} can be recommended for the cultivation of short duration cassava variety Vellayani Hraswa. The latter nutrient management practice has the added advantage of reducing the fertilizer load in soil and pollution at the same time contributing to soil health and sustenance. The improved yields in cassava with

Table 3. Effect of biofertilizer and levels of nutrients on yield and harvest index in cassava

Treatments	Number of tubers per plant	Mean tuber weight (kg)	Tuber yield per plant (kg)	Tuber yield (Mg ha^{-1})	Top yield (Mg ha^{-1})	Harvest Index
Biofertilizer (B)						
b_1 - PGPR (L) 2 %	7.85	0.62	4.61	41.31	16.36	0.72
b_2 - PGPR (L) 5 %	8.74	0.67	5.00	43.12	16.71	0.79
b_3 - PGPR (P)	7.78	0.45	4.15	39.05	14.58	0.70
b_0 - Without biofertilizer	6.59	0.49	3.47	37.60	14.38	0.67
CD (0.05)	0.260	0.048	0.237	1.013	0.858	0.062
Levels of nutrients (N)						
n_1 - 50 % RDN	6.53	0.51	4.09	38.23	15.42	0.67
n_2 - 75 % RDN	8.86	0.59	4.77	42.11	15.82	0.72
n_3 - 100 % RDN	7.83	0.52	4.36	41.07	15.29	0.70
CD (p=0.05)	0.205	0.043	0.196	0.594	NS	0.042

*See Table 1 for details

Table 4. Effect of interaction on yield and harvest index in cassava

B × N Interaction	Number of tubers per plant	Mean tuber weight (kg)	Tuber yield per plant (kg)	Tuber yield (Mg ha^{-1})	Top yield (Mg ha^{-1})	Harvest Index
b_1n_1	6.22	0.64	4.17	38.83	14.55	0.68
b_1n_2	8.78	0.58	4.28	40.16	17.09	0.70
b_1n_3	8.56	0.62	4.69	42.32	16.76	0.73
b_2n_1	5.67	0.65	4.21	39.27	17.67	0.69
b_2n_2	10.00	0.78	5.12	44.49	17.92	0.78
b_2n_3	8.67	0.44	4.16	39.54	15.23	0.72
b_3n_1	8.67	0.45	4.11	38.56	14.24	0.69
b_3n_2	9.18	0.39	4.13	39.28	14.29	0.71
b_3n_3	7.55	0.52	4.15	38.06	15.55	0.70
b_0n_1	5.55	0.55	3.42	36.01	13.56	0.67
b_0n_2	7.66	0.43	3.83	37.78	14.04	0.68
b_0n_3	6.56	0.52	3.91	38.01	15.21	0.69
CD (p=0.05)	0.450	0.066	0.393	1.752	1.475	0.042

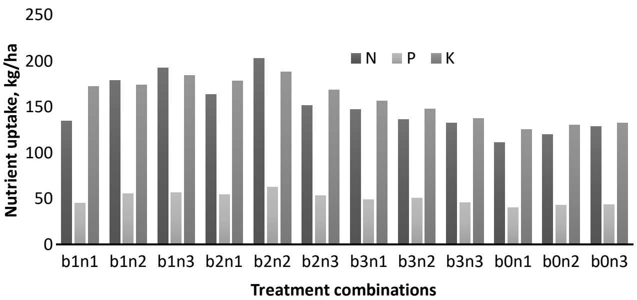

Fig. 2. Nutrient uptake in cassava as influenced by interaction of biofertilizers and different nutrient levels

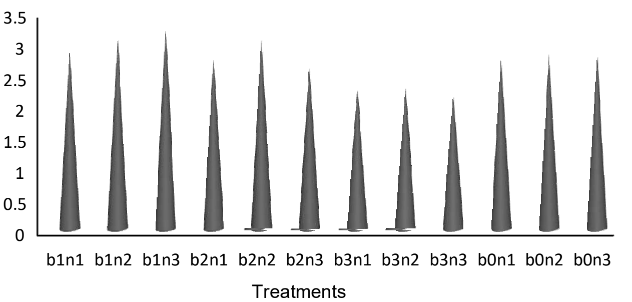

Fig. 3. Effect of biofertilizer x nutrient levels on the economics

the use of liquid formulation at 5 % concentration of the consortium biofertilizer and the 25 % saving in chemical fertilizers portray the sustainability and economic benefits of the practice in the tuber cultivation.

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