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Yield attributes of Cassava (*Manihot esculenta* Crantz) and soil properties in Southern Laterites, Kerala as influenced by consortium biofertilizers

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ABSTRACT

A field experiment was undertaken at College of Agriculture, Vellayani during June to December 2019, to assess the efficacy of liquid consortium biofertilizer, Plant Growth Promoting Rhizobacteria (PGPR) Mix - I in cassava and to examine the changes in soil chemical and biological properties with the application. The treatment combinations included four levels of biofertilizer [PGPR Mix - I liquid (L) @ 2 %, PGPR Mix - I liquid (L) @ 5 %, PGPR Mix - I powder (P) formulation @ 10g of 2 % mixture per plant, without biofertilizer] and three levels of nutrients, with 50: 50: 100 kg NPK/ha as the standard dose of nutrients (SDN), [50 % SDN, 75 % SDN, 100 % SDN]. The 4 × 3 factorial experiment was laid out in randomized block design with three replications. The results of the study revealed that the liquid biofertilizer consortium at 5 per cent + 75 percent SDN (37.5: 37.5: 75 kg NPK /ha) recorded significantly superior yield attributes in cassava and improved the soil organic C, available K status and microbial count.

Introduction

The COVID 19 pandemic has invoked an element of uncertainty in all frontiers of life. Malnutrition has succumbed the weaker sections to fatality, food security is under threat and nutritional insecurity is sure to add to the catastrophe. This coupled with the unprecedented climate change events and challenges in agriculture production scenario have sparked the interest in energy efficient, high biomass producing resilient crops to sustain the food and dietary requirements of the in mass population worldwide. Carbohydrate rich nutritive tuber crops partly offer solution to the impasse on account of their low input and management requirements, adaptability to marginal lands and global warming and high yield potential. Cassava, the most important tuber crop of the tropics is climate resilient and with its high bioconversion efficiency fosters food and nutritional security in many countries. The production of cassava globally and in India is 311.5 mt and 4.98 mt respectively (Radhakrishnan *et al*., 2022). While, in Kerala, the production of cassava is 259.26 t (FIB, 2022). Being a concentrated source of carbohydrate, cassava can effectively bridge the likely demand - supply gap in major food grains. Extensive studies on the fertility status of the soils in Kerala (KSPB, 2013) have documented an acidic pH in majority of the soils of the state coupled with a high P status (> 25 kg/ha) and low to medium N and K contents in the Southern Laterites of the state. Amelioration of the soil acidity with lime materials and inclusion of biofertilizers in the nutrient management package can mobilize the fixed forms of the nutrients in soil (P and K) and the atmosphere (N) thus ensuring its availability over a longer period. The conventional practice of using microbial inoculants is in the form of carrier based formulations, especially talc. One of the major challenges encountered during the development of biofertilizers and commercialization of an effective strain is its shelf

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life and purity of inoculants (Basu *et al.,* 2021). Brar *et al*. (2012) opined that compared to the powder form of biofertilizers, liquid formulations are more advantageous on account of its ease in use, longer shelf life and compatibility in micro irrigation systems. The Department of Agricultural Microbiology, College of Agriculture, Vellayani has developed a liquid formulation of biofertilizer, PGPR Mix – I, which is a consortium of nitrogen (N) fixers (*Azospirillum lipoferum, Azotobacter chroococcum*), phosphorus (P) solubiliser (*Bacillus megaterium*) and potassium (K) solubiliser (*Bacillus sporothermodurans*).

Use of biofertlizers is of practical significance in cassava as the crop is of 6-10 months duration and depletes the nutrients in the soil even when the available nutrient status is high. Therefore a field experiment was undertaken in cassava (*Manihot esculenta* Crantz), to assess the efficacy of PGPR formulations on yield attributes of cassava and soil properties in Southern Laterites.

Material and Methods

Experimental site and conditions

The project work was undertaken at College of Agriculture, Vellayani, located at 8°30'N latitude, 76°54'E longitude and at an altitude of 29 m above mean sea level during June to December 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) and K (138.32 kg/ha) and high in P (42.63 kg/ha) before the layout of experiment. The experiment was laid out in factorial Randomized Block Design with two factors, biofertilizers [PGPR Mix -I liquid (@ 2 % ; PGPR Mix -I liquid (@ 5 %; PGPR Mix -I powder @ 10 g of 2 % mixture per plant ; without biofertilizer] and nutrient levels [50 %; 75 % ; 100 % of standard dose of nutrients (SDN), 50:50:100 kg NPK /ha].Cassava setts (20 cm long cuttings of stem, 4-5 noded) of short duration variety Vellayani Hraswa, (5-6 months) were planted with two nodes of each sett below the soil and remaining nodes above, at a spacing of 90 cm x 90 cm. 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.

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 200 mL 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.

Yield attributes

The crop was ready for harvest, six months after planting (MAP). The percentage of productive roots per plant was calculated by dividing the number of tuberous roots by the total number of roots in each plant at harvest and multiplying by 100. Tubers were cut from the base of the stem and the length and girth of ten randomly selected tubers in each treatment were measured and recorded. Fresh weight of each part of the harvested plant (stem, leaves and tuber) was taken and sub samples were made for estimating the dry weight. The sub samples were dried in an oven at 70 ± 5°C to constant dry weight and weight of each part was computed. To record the dry matter production (DMP).

Soil analysis

Samples were collected from the treatment plots at 1-15 cm depth at harvest, air dried and sieved through 2 mm sieve for the chemical analysis (soil pH, available N, P and K) and through 0.5 mm sieve for the estimation of soil organic carbon (C). Soil pH was determined in a 1: 2.5 w/v soil -water extract using pH meter and organic C by Walkley-Black chromic acid wet oxidation method and expressed in percentage. Available N was estimated by distillation with alkaline potassium permanganate, Bray extractable P by ammonium molybdo-blue colour method and K, by flame photometry with neutral normal ammonium acetate as extractant. Microbial counts, bacteria, fungi and actinomycetes were enumerated in the fresh soil samples by serial dilution method (Gopal, 2018).

Statistical analysis

The experimental data were statistically computed by applying the technique of analysis of variance (ANOVA) for 4 x 3 factorial RBD experiment and the significance was tested by F test (Cochran and

Cox, 1992) using OP Stat software, an online agriculture data analysis tool developed by O. P. Sheoran, Computer Programmer, Hisar.

Results and Discussion

Yield attributes in cassava

Biofertilizer application had significant influence on percentage of productive roots, length of tuber, girth of tuber and DMP in cassava (Table 1). The percentage of productive roots (56.96), tuber length (40.37 cm) and tuber girth (16.69 cm) were found to be superior in treatment with 5 % PGPR. (L). Formulation of PGPR (L) 2 % recorded the highest DMP (2.19 kg per plant) which was on par with 5 % PGPR (L) application.

Table 1: Effect of biofertilizer and nutrient levels on yield attributes

Treatments	Percentage of productive roots	Length of tuber (cm)	Girth of tuber (cm)	Dry matter production (kg per plant)
Biofertilizer (B)				
b_1 - PGPR (L) 2 %	50.96	38.85	15.39	2.19
b_2 - PGPR (L) 5 %	56.49	40.37	16.69	2.18
b_3 - PGPR (P)	53.28	34.30	13.78	1.81
b_0 - without biofertilizer	54.33	35.37	13.57	1.51
SEm±	0.25	0.18	0.04	0.04
CD (0.05)	0.764	0.554	0.125	0.105
Level of nutrients, NPK (N)				
n_1 - 50 % SDN	51.38	36.95	14.14	1.78
n_2 - 75 % SDN	54.06	38.47	15.42	2.08
n_3 - 100 % SDN	55.80	36.63	14.56	1.91
SEm±	0.22	0.16	0.01	0.03
CD (0.05)	0.661	0.480	0.029	0.091

***L- Liquid P- PowderSDN- 50: 50: 100 kg NPK/ha**

The nutrient application with 75 % SDN recorded the highest tuber length, girth and DMP, 38.47 cm, 15.42 cm and 2.08 kg per plant respectively. The percentage of productive roots were significantly superior in treatment with 100 % SDN. Among the treatment combinations (Table 2), the highest percentage of productive roots was observed in PGPR (L) 5 % + 100 % SDN. The length of tuber, girth of tuber and DMP were significantly superior for the treatment combination of PGPR (L) 5 % + 75 % SDN, 43.45 cm, 18.37 cm and 2.66 kg per plant respectively.

The positive influence of consortium biofertilizers on growth and yield of tuber crops have been illustrated by several workers (Dhanya, 2011; Jayapal, 2012; Radhakrishnan *et al*., 2013; Suja *et al*., 2014). The use of consortium biofertilizer in combination with chemical fertilizers significantly increased the yield attributes over the sole chemical fertilizer application. Further, it has been documented that the microorganisms in the consortium biofertilizers have the ability to synthezise phyto-hormones, decompose organic matter and recycle essential elements, augment the soil flora and improve the soil structure for root development (Singh, 2013). It is hence presumed that the enhanced root proliferation and absorption of water and nutrients, consequent to the PGPR application resulted in better plant yield parameters and DMP.

Table 2: Interaction effect of biofertilizer and nutrient levels on yield attributes

B × N Interaction	Percentage of productive roots	Length of tuber (cm)	Girth of tuber (cm)	Dry matter production (kg per plant)
b_1n_1	51.11	37.11	14.31	1.82
b_1n_2	58.30	39.89	16.56	2.31
b_1n_3	50.96	39.55	15.30	2.43
b_2n_1	48.95	40.78	16.28	2.07
b_2n_2	53.31	43.45	18.37	2.66
b_2n_3	61.96	36.89	15.39	1.82
b_3n_1	51.04	35.11	13.40	1.82
b_3n_2	52.23	34.00	13.15	1.80
b_3n_3	56.58	33.79	14.78	1.82
b_0n_1	54.41	32.00	12.56	1.43
b_0n_2	54.06	36.56	13.58	1.55
b_0n_3	54.54	37.56	14.56	1.56
SEm±	0.44	0.32	0.03	0.06
CD (0.05)	1.322	0.960	0.078	0.181

Vendan and Thangaraju (2006) documented the advantages of liquid formulations of biofertilizers over powder formulation *viz*., 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.In addition, as a higher cell count is realized in the liquid formulation, the dosage requirement for application can be reduced by 10 folds as compared to carrier based biofertilizers. Maheswari and Elakkiya (2014) reported the positive effects of foliar spray of liquid biofertilizer in black gram, on growth attributes and biochemical constituents such as chlorophyll, carbohydrate, protein and carotenoids content. It is deduced that cassava variety Vellayani Hraswa, being a crop of longer duration (180 days) required a higher concentration (cell count) to realize the benefits of the formulation. This is justified by the significantly superior results on growth and yield parameters attained in the present study with the application of 5 per cent biofertlizer consortium. In addition to this, it is inferred that the cell protectants present in the liquid cultures helped to increase the survival of beneficial bacteria which play a vital role in nutrient uptake as enumerated by Krishan *et al.* (2005). The better performance of liquid biofertilizers over carrier based formulations has also been reported by other workers (Maheswari and Kalayarasi, 2015; Gopal, 2018; Lakshmi *et al*., 2019).

Soil properties

Soil organic carbon, available N, P and K content

The results on post experiment soil organic carbon, available N, P and K status as influenced by effect of biofertilizer, level of nutrients (NPK) and their interactions are presented in Tables 3 and 4.

Table 3: Effect of biofertilizer and nutrient levels on soil nutrient status after the experiment

Treatments	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Biofertilizer (B)				
b_1- PGPR (L) 2 %	1.44	264.95	53.72	211.56
b_2 - PGPR (L) 5 %	1.47	244.03	52.97	191.16
b_3 - PGPR (P)	1.45	209.71	59.20	223.70
b_0 - without biofertilizer	1.29	204.17	46.09	186.60
SEm±	0.01	14.30	2.11	1.63
CD (0.05)	0.031	42.201	6.235	4.818
Level of nutrients, NPK (N)				
n_1 - 50 % SDN	1.14	219.63	51.47	206.76
n_2 - 75 % SDN	1.37	240.54	56.93	192.81
n_3 - 100 % SDN	1.40	235.31	54.26	196.56
SEm±	0.009	12.38	1.89	1.41
CD (0.05)	0.027	NS	NS	4.172

***L- Liquid P- Powder SDN- 50: 50: 100 kg NPK/ha**

Organic carbon in soil was found to vary significantly with PGPR Mix-I application and the treatment PGPR (L) 5 %, recorded the highest content (1.47 %) and was on par with PGPR (L) 2 % and PGPR (P), the values being 1.44 per cent and 1.45 per cent respectively. The lowest carbon (1.29 %) was observed in the treatment without biofertilizer. The mean data corresponding to effect of the levels of nutrients revealed that the organic carbon content was influenced by full dose SDN and was on par with 75 per cent of SDN with values 1.40 per cent and 1.37 per cent respectively. Among the interaction effect the highest organic carbon content (1.64 %) was observed in combination of PGPR (L) 5 % + 75 % SDN.

Table 4: Interaction effects on soil nutrient status after the experiment

B×N Interaction	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
b_1n_1	1.24	230.08	47.74	182.49
b_1n_2	1.52	251.00	58.63	178.64
b_1n_3	1.51	251.00	60.79	184.67
b_2n_1	1.35	231.48	57.20	175.64
b_2n_2	1.64	292.83	66.55	177.32
b_2n_3	1.41	271.92	55.84	185.00
b_3n_1	1.05	209.17	54.89	226.47
b_3n_2	1.09	271.91	54.70	217.87
b_3n_3	1.54	212.67	50.01	209.31
b_0n_1	0.90	209.17	46.05	196.83
b_0n_2	1.23	206.17	47.85	189.39
b_0n_3	1.16	217.16	50.38	194.26
SEm±	0.02	24.76	3.67	2.83
CD (0.05)	0.054	NS	NS	8.344

The variations in available N status of the soil with treatments were significant. Among the biofertilizer treatments, the use of liquid PGPR (L) 2 % (b_1) resulted in a significantly higher soil N status (264.95 kg/ha) which was on par with the 5 % treatment (244.03 kg/ha). The lowest N content was observed in b_0 (204.17 kg/ha) that was statistically comparable to powder formulation of PGPR (209.71 kg/ha). However, the different levels of nutrients and interaction failed to bring about marked variations in available N status post the experiment. The statistically analysed data revealed that biofertilizer application significantly influenced the P status and higher values were recorded in the treatments in which PGPR Mix-I was used. Among these, powder formulation PGPR recorded the highest soil P value (59.20 kg/ha). It was on par with PGPR (L) 2 % and PGPR (L) 5 % with values 53.72 kg/ha and 52.97 kg/ha respectively. The different levels of NPK and interaction did not exert any significant influence on soil P status.

Potassium content in soil differed significantly with the two factors and their interaction. Significantly superior K status (223.70 kg/ha) was recorded in the treatment PGPR (P) and 50 % SDN, 206.76 kg/ha. The significant influence of the treatment combinations was revealed and the combination PGPR (P) + 50 % SDN, recorded the superior value of 226.47 kg K ha^{-1}. Soil available N status was lowered from the initial level and is ascribed to the crop uptake. Nevertheless, the P and K status were higher than the initial status. Meenakumari *et al.* (2008) reported the efficiency of P solubilizers in enhancing soil P pool by solubilizing P from insoluble sources. The PSB secretes the different organic acids which act on insoluble phosphate to convert them into soluble phosphate near the root of the plant and hence, availability of P is increased. Further, the mycotrophic nature of cassava makes it efficient in P extraction from the soil with the symbiotic association between its roots and AMF (Howeler, 2001). This also minimizes P depletion. A similar trend was noticed with K.

Potassium is considered as the most limiting factor in cassava system (Ezui, 2017) and the key nutrient for cassava cultivation. The nutrient is highly dynamic in soil. The results of *in vitro* assessment of K solubilization by *Bacillus sporothermodurans* present in liquid consortium indicated the high efficiency of the bacterium to solubilize insoluble inorganic (non exchangeable and fixed) K (Gopi, 2018), by its inherent ability to release organic acids that effectuates the solubilisation. This could be the plausible reason for higher available K in soil despite the higher uptake. The treatment with half the dose of SDN recorded the highest available K among the different nutrient levels. This can be related to the lower uptake of K in this treatment. The available N and P status of the soil did not show considerable variation with application of inorganic fertilizers. This was in conformity with the findings of Radhakrishnan *et al.* (2013). The interaction effects were significant with respect to organic carbon content and available K alone.

Microbial Count

Significant variations in the bacterial, fungal and actinomycete counts were observed with PGPR applications (Table 5 and 6) and the liquid formulations could enhance the microbial activities better than the powder formulation. Enumeration of the microbial counts in the rhizosphere revealed the population to be higher in the treatment with liquid consortium biofertilizer (PGPR Mix - I) indicating their proliferation and increased activity in the soil. Gopi *et al.* (2020) based on the results of analysis of rhizosphere population after application of PGPR Mix - I in amaranthus, reported successful colonization of organisms of PGPR Mix - I.

Table 5: Effect of biofertilizer and levels of nutrients on soil microbial count

Treatments	Microbial count (cfu/g soil)		
	Bacteria (x 10^6)	Fungi (x 10^4)	Actinomycetes (x 10^4)
Biofertilizer (B)			
b_1 - PGPR (L) 2 %	42.89	18.98	29.43
b_2 - PGPR (L) 5 %	44.11	20.44	28.11
b_3 - PGPR (P)	40.00	16.83	26.16
b_0-without biofertilizer	31.48	13.33	22.38
SEm±	0.57	0.49	0.63
CD (0.05)	1.686	1.466	1.887
Level of nutrients (N)			
n_1 - 50 % SDN	37.33	12.58	23.33
n_2 - 75 % SDN	37.91	15.83	24.74
n_3 - 100 % SDN	35.33	13.08	22.91
SEm±	0.50	0.43	0.55
CD (0.05)	1.460	1.270	NS

***L- Liquid P- Powder SDN- 50: 50: 100 kg NPK/ha**

Table 6: Interaction effects on soil microbial count

B ×N Interaction	Microbial count (cfu g^{-1} soil)		
	Bacteria (x 10^6)	Fungi (x 10^4)	Actinomycetes (x 10^4)
b_1n_1	38.27	16.13	24.67
b_1n_2	39.32	14.67	24.33
b_1n_3	42.12	15.95	23.00
b_2n_1	41.29	20.03	29.00
b_2n_2	43.33	21.67	26.53
b_2n_3	40.47	19.67	29.51
b_3n_1	38.23	15.00	25.67
b_3n_2	35.91	13.67	26.33
b_3n_3	36.67	13.52	23.33
b_0n_1	34.13	11.67	23.59
b_0n_2	31.21	12.75	22.67
b_0n_3	32.67	10.33	21.00
SEm(±)	0.989	0.53	1.10
CD (0.05)	2.021	1.372	NS

Among the microbes assessed, bacterial, fungal and actinomycetes counts were found to be significantly the highest in b_2 [PGPR (L) 5 %] followed by b_1 [PGPR (L) 2 %]. As expected, the lowest counts were observed in the treatment which did not receive any biofertilizer addition but was higher than the initial count. It is inferred that the rhizospheric deposits of root exudates, mucilage polysaccharides, phyto-hormones etc. produced by cassava would have promoted microbial activity, but, not to the extent of augmentation as evidenced with biofertilizer application. Microbial associations in cassava studied by Arotrupin and Akinyosoye (2008) revealed the array of microorganisms in cassava cultivated soils and Suja *et al.* (2014) reported the potential of the rhizobacteria for plant growth promotion and biocontrol. Dotaniya and Meena (2015) documented that plants can release carbohydrates, amino acids, lipids, and vitamins through their roots to stimulate the activities of microorganisms in the soil. Variations in the total microbial count due to application of different level of nutrients depicted in Table 5, reveal that the bacterial population was the lowest with application of full dose of SDN. The use of higher doses of fertilizers like urea increases ammonium toxicity in bacteria (Damodaran *et al*., 2016), whereas P and K fertilizers, reduce the substrate induced respiration in bacteria (Bolan *et al*., 1996). The growth of fungi decreases in N depleted conditions (Tuomela *et al.,* 2000) and this supports the results on fungal population with NPK application observed in this study. With respect to interaction, the bacterial and fungal counts varied significantly with the interaction of 5 % PGPR (L) and 75 % SDN. This indicates the positive interaction of consortium biofertilizer and nutrients. Khipla *et al*. (2017) documented the highest soil microbial population and enzyme activities with application of 100 % chemical fertilizers along with the consortium of *Azotobacter* and phosphate solubilizing bacteria in poplar. Variations in the actinomycete count due to the different level of fertilizers and interaction failed to reach the level of significance.

Conclusion
Optimisation of nutrient dose is important for improving the nutrient use efficiency and reducing losses. Cassava is a heavy feeder of nutrients and often leads to the depletion of the soil fertility unless replenished through efficient nutrient management practices. Inclusion of consortium biofertilizers in the nutrient management practice of short duration cassava has proven to be an effective strategy for enhancing the yield attributes and sustaining soil properties. Considering the impacts on yield parameters and soil fertility, application of PGPR Mix I liquid formulation (5 %) along with 37.5: 37.5: 75 kg NPK ha^{-1} can be recommended for short duration varieties of cassava.

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Conflict of interest
The authors declare that they have no conflict of interest.

References
Arotupin, D. J. & Akinyosoye, F. A. (2008). Microbiological and physicochemical characteristics of cassava cultivated soils. *Research Journal of Microbiology, 3*(1), 41-46.

Basu, A., Prasad, P., Das, S. N., Kalam, S., Sayyed, R. Z., Reddy, M. S. & El Enshasy, H. (2021). Plant growth promoting rhizobacteria (PGPR) as green bioinoculants: recent developments, constraints, and prospects. *Sustainability*, *13*(3), 1140.

Bolan, N. S., Curri, L. D. & Baskaran, S. (1996). Assessment of the influence of phosphate fertilizers on microbial activity in pasture soil. *Biology and Fertility of Soils*, *21*, 284-292.

Brar, S. K., Sarma, S. J. & Chaabouni, E. (2012). Shelf-life of biofertilizers: An accord between formulations and genetics. *Journal of Biofertilizers and Biopesticides*, *3*(5), 32- 38.

Cochran, W. G. & Cox, G. M. (1992). Experimental Designs. Asia Publishing House, Bombay.

Damodaran, T., Bagyaraj, D. J. & Revanna, A. (2016). Effect of chemical fertilizers on the beneficial soil microorganisms. *Fertilizer Environmental News*, *2*(2), 10-11.

Dhanya, T., (2011). Production technology for organic sweet potato. M.Sc.(Ag) thesis submitted to Kerala Agricultural University, Thrissur, Kerala.

Dotaniya, M. L. & Meena, V. D. (2015). Rhizosphere effect on nutrient availability in soil and its uptake by plants: A review. Proceedings of the National Academy of Sciences, India, *85*, 1-12.

Ezui, K. S., (2017). Understanding the productivity of cassava in West Africa. Ph.D. thesis submitted to Wageningen University.

FIB. (2022). Farm Guide. (2022). Farm Information Bureau, Agriculture Development and Farmers' Welfare Department, Government of Kerala, Kowdiar, Thiruvananthapuram.

Gopal, S. K., (2018). Liquid Formulation of *Azospirillum* sp. and Phosphate Solubilizing Bacteria (PSB) performed better than carrier based formulations on the growth of *Amaranthus* sp. under field conditions. *Research Journal of Agricultural Science*, *9*,316–321.

Gopi, G. K., Meenakumari, K. S., Anith, K. N., Nysanth, N. S. & Subha, P. (2020). Application of liquid formulation of a mixture of plant growth promoting rhizobacteria helps reduce the use of chemical fertilizers in Amaranthus (*Amaranthus tricolor* L.). *Rhizosphere, 15*, 1002-1012.

Gopi, G., (2018). Standardisation of liquid formulation of PGPR Mix 1 and its evaluation for plant growth promotion in Amaranthus (*Amaranthus tricolor* L.). M.Sc.(Ag) thesis submitted to Kerala Agricultural University, Thrissur, Kerala.

Hoe, P. C. K. & Rahim, K. A. (2010). Multifunctional liquid biofertilizer as an innovative agronomic input for modern agriculture. In: Proceedings of the Research and Development Seminar, Nuclear Malaysia, Kajang, Selangor.

Howeler, R. H. (2001). Cassava mineral nutrition and fertilization. In: Hillocks, R. J., Tresh, J. M. and Bellotti, A. C. (eds), Cassava: Biology, Production and Utilization. CABI Publishing, Oxon, UK and New York, USA.

Jayapal, A. (2012). Production technology for organic coleus. M.Sc.(Ag) thesis submitted to Kerala Agricultural University, Thrissur, Kerala.

Khipla, N., Gosal, S. K. & Gill, R. I. S. (2017). Influence of biofertilizers and inorganic fertilizers on soil microbial population and enzyme activities in rhizosphere of poplar. *Chemical Science Review and Letters*, *6*(24), 2324-2331.

Krishan, C., Greep, S. & Sreevastha, R. S. H. (2005). Liquid biofertilizers- Solution for longer shelf-life. Spice India, *32*, 29-32.

KSPB (Kerala State Planning Board) (2013). Soil Fertility Assessment and Information for enhancing Crop Productivity in Kerala. Kerala State planning Board, Thiruvananthapuram, Kerala.

Lakshmi, A., Sireesha, T., Sreelatha, M. & Bharatha, L. P. (2019). Jamuna Comparative efficacy of liquid biofertilizers over carrier based formulations in sugarcane plant – ratoon sequence. *International Journal* of *Advanced Research* in *Biological Sciences*, *9*(4), 298-301.

Maheswari, N. U. & Kalaiyarasi, M. (2015). Comparative study of liquid biofertilizer and carrier based biofertilizer on green leafy vegetables. *International Journal of Pharmaceutical Sciences Review and Research*, *33*(1), 229-232.

Maheswari, U. N. & Elakkiya, T. (2014). Effect of liquid biofertilizers on growth and yield of *Vigna mungo* L. *International Journal of Pharmaceutical Sciences Review and Research*, *29*(2), 42-45.

Meenakumari, K. S., Sivaprasad, P. & Geegi, M. T. (2008). Role of phosphate solubilizing microorganisms in P dynamics of soil system. In: Sivaprasad, P. and Meenakumari, K. S. (eds.), Microbial Inoculant Technology for Sustainable Farming. Kalyani publishers, Ludhiana, India.

Radhakrishnan, A.S., Suja, G. & Sreekumar, J. (2022). How sustainable is organic management in cassava? Evidences from yield, soil quality, energetics and economics in the humid tropics of South India. *Scientia Horticulturae*, *293*, 110723.

Radhakrishnan, S. A. R, Suja, G. & Anil, A. T. (2013). Organic vs conventional management in cassava: growth dynamics, yield and soil properties. *Journal of Root Crops, 39*(2), 93-99.

Singh, J. S. (2013). Plant growth promoting rhizobacteria: Potential microbes for sustainable agriculture. *Resonance*, 18(3), 275-281.

Suja, S.P., Hegde, V., Makeshkumar, T. & Anjana Devi, I. P. (2014). Screening of rhizobacteria associated with cassava for plant growth promotion and biocontrol potential. *Journal of. Root Crops*, *40*(1), 1-8.

Tuomela, M., Vikman, M., Hatakka, A. & Itävaara, M. (2000). Biodegradation of lignin in a compost environment: A review. *Bioresource Technology*, *72*(2), 169- 183.

Vendan, R. & Thangaraju, M. (2006). Development and standardization of liquid formulation for Azospirillum bioinoculant. *Indian Journal of Microbiology*, *46*, 379–387.

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